LOMA LINDA UNIVERSITY
School of Science and Technology
in conjunction with the
Faculty of Graduate Studies

Neuropsychological Symptoms Associated with Multiple Shunts

by

Jared Jackson

A dissertation submitted in partial satisfaction of
the requirements of the degree of
Doctorate of Philosophy in Clinical Psychology

December 2010

Each person whose signature appears below certifies that this dissertation in his/her opinion is adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Susan A. Ropacki

____, Chairperson
Susan A. Ropacki, Associate Professor of Psychology

____
Travis G. Fogel, Assistant Professor of Physical Medicine, School of Medicine

Paul Haerich

____
Paul E. Haerich, Professor of Psychology

____
Jason E. Owen, Associate Professor of Psychology

____
Alexander Zouros, Associate Professor of Neurosurgery, School of Medicine

CONTENTS

ABSTRACT OF THE DISSERTATION

Neuropsychological Symptoms Associated with Multiple Shunts

By

Jared Jackson

Doctorate of Philosophy, Graduate Program in Clinical Psychology
Loma Linda University, December 2010
Dr. Susan A. Ropacki, Chairperson

Abstract

Hydrocephalus is the excessive accumulation of cerebrospinal fluid within the cranium which may result in increased intracranial pressure, dilation of cerebral ventricles and displacement of adjacent brain structures. Ventriculoperitoneal shunting is often needed to treat hydrocephalus. Patients with ventriculoperitoneal shunts have been found to have IQ scores below the mean of the general population. In addition, many of these patients experience shunt infections or other complications that require shunt replacement. Shunt replacements and shunt infections have been associated with additional deficits in intellectual functioning. However, previous research has failed to address the neuropsychological ramifications of shunt infections and shunt replacements. Given the high prevalence of hydrocephalus in patients with spina bifida, this patient population was chosen for this study. Results from this study indicate a significant correlation between shunt replacements and deficits in general intelligence, visuospatial skills, and memory functioning in children with spina bifida. Shunt infections were not significantly related to any aspect of neuropsychological functioning. However, patients with a history of shunt infection generally receive a greater number of shunt replacements

than patients without a history of shunt infection, and thus display lower intellect and more visuospatial and memory deficits.

Introduction

Hydrocephalus is the excessive accumulation of cerebrospinal fluid (CSF) within the cranium which may result in increased intracranial pressure, dilation of cerebral ventricles and displacement of adjacent brain structures. There are many different etiologies of hydrocephalus, some being congenital, and others being acquired later in life. Spina bifida is a congenital neuro-tube defect commonly associated with hydrocephalus. Chiari II malformation is usually associated with spina bifida and is the root cause of the hydrocephalus in these patients. This study examined hydrocephalus in spina bifida patients and how shunting, shunt replacement, and shunt infections affect their neuropsychological functioning.

Ventriculoperitoneal shunting is often needed to treat hydrocephalus (Victor & Ropper, 2001; Del Bigio, 1993), regardless of the etiology of the hydrocephalus. While shunting is essential in treating some individuals with hydrocephalus, the shunt surgery, shunt placement, and any shunt revision may also affect one's neuropsychological functioning. The effect shunting has on one's neuropsychological functioning is not totally understood. It is postulated, however, that shunt placement and shunt revision impairs neuropsychological functioning beyond the brain abnormalities associated with hydrocephalus. Hydrocephalus and the associated neuropsychological symptoms are addressed below.

Hydrocephalus

Hydrocephalus is the excessive accumulation of cerebrospinal fluid (CSF) within the cranium which may result in increased intracranial pressure, dilation of cerebral ventricles and displacement of adjacent brain structures. This excessive accumulation of CSF is due to an obstruction of CSF flow at some point in its ventricular pathway or aqueduct. This blockage may occur at the medullary foramens of Luschka and Magendie or in the basal subarachnoid space (Menkes, 2000; Victor & Ropper, 2001). There are many other possible etiologies for this condition. Hydrocephalus may be caused by obstruction of cerebrospinal fluid pathways due to neurologic abnormalities, intracranial hemorrhages, central nervous system infections, neoplasms in the brain, craniocerebral trauma, and other conditions (Menkes, 2000; Victor & Ropper, 2001). To help classify the nature of a patient's hydrocephalus, a prefix is often added to designate the site of the presumed obstruction. For example, a patient may be diagnosed with obstructive hydrocephalus or aqueductal-obstructive hydrocephalus (Victor & Ropper, 2001). Some clinical manifestations of hydrocephalus may include intracranial hypertension, headache, lethargy, urinary incontinence, ataxia, gate disturbance, and macrocephaly in infants (Menkes, 2000; Victor & Ropper, 2001).

In certain etiologies it is possible for hydrocephalus to reach a non-progressive, stable stage. In this circumstance, it is thought that the brain has learned to compensate for the block in CSF flow. This can be accomplished from a decrease in CSF production, or an increase in CSF absorption. In these cases the patient's intracranial pressure can gradually decline to a point that falls into the high average range. This state is called normal-pressure-hydrocephalus. However, despite the decline in intracranial pressure these patients still manifest the cerebral effects of a hydrocephalic state. This is due to that fact that while no surgical methods are needed to regulate their intracranial pressure, there is some displacement of brain structures due to their hydrocephalic state (Menkes, 2000; Victor & Ropper, 2001). Although patients with normal-pressure-hydrocephalus may display the effects of hydrocephalus, they are able to escape the many possible complications associated with surgical interventions (shunting).

Literature Review

Etiologies of Hydrocephalus

Spina bifida. Spina bifida is a neural tube defect marked by a congenital cleft of the spinal column (Victor & Ropper, 2001). It is one of the most common disabling birth defects in the United States. An estimated seven out of every 10,000 births have spina bifida. Currently, there are over 70,000 people in the United States with spina bifida (Landry, Jordan, and Fletcher, 1994). In addition to spinal column defects, spina bifida patients have also been noted to have congenital brain malformations. Spina bifida patients have been found to have lower volume in the prefrontal cortex, reduced neuro-connectivity in the parenchyma, and lower density in parietal lobe white matter tracts (Fletcher, Copeland, Fredrick, Blaser, Kramer, Northrup, et.al, 2005; Menkes, 2000; Victor & Ropper, 2001). Research using diffusion tensor imaging has noted impairments in myelination and abnormalities in axonal characteristics and extra-axonal/extracellular space in the association pathways of children with spina bifida (Hasan, Eluvathingal, Kramer, Ewing-Cobbs, Dennis, and Fletcher, 2008). In addition, spina bifida is frequently associated with hydrocephalus and accounts for more than 70% of all hydrocephalus cases (Landry, Jordan, and Fletcher, 1994).

Chiari malformations. Most patients with spina bifida also have a Chiari malformation, which commonly results in hydrocephalus (Victor & Ropper, 2001). Chiari malformations are congenital abnormalities at the base of the brain. These abnormalities are often expressed as a herniation of the lower brainstem and cerebellar tonsils through the foramen magnum. A displacement of the medulla and lower part of the forth-ventricle into the cervical canal is also commonly found (Victor & Ropper, 2001).

There are four types of Chiari malformations, with type II being the most common. Its identifying features are compression of the medulla and cerebellar tonsils into the upper cervical spinal canal through the foramen magnum. This type of malformation is usually associated with spina bifida. Type I features are similar but the cerebellomedullary malformations are less severe. Type I malformations have been noted in patients with and without spina bifida. Type III has similar features to type II and mainly presents as cerebellar herniation with a high cervical or occipitocervical spina bifida. Type IV consists only of cerebellar hypoplasia. Some clinical manifestations of types I-IV may include but are not limited to hydrocephalus, headache, vertigo, vocal cord paralysis, apnea, nystagmus, swallowing difficulties and ataxia (Menkes, 2000, Victor & Ropper, 2001).

In addition to the brain abnormalities characteristic of the Chiari malformations, there are other associated morphologic features. Patients with Chiari malformations have an elongated medulla and pons and the aqueduct is narrowed. The displacement of the medulla and cerebellum occludes the foramen magnum. The cerebellum is misshapen and displaced causing the cistera magna to be eradicated. Subsequently, the Luschka and Magendie open into the cervical canal, and the arachnoid tissues around the herniated brainstem and cerebellum become fibrotic (Menkes, 2000, Victor & Ropper, 2001).

These abnormalities are likely responsible for the development of hydrocephalus which is present in almost all patients with Chiari malformations. The severity of the hydrocephalus is thought to be related to the degree of brain morphing. Patients with type II and the associated spina bifida are faced with the problem of progressive hydrocephalus. If left untreated, extensive brain damage or death may occur (Menkes, 2000; Victor & Ropper, 2001). In patients with spina bifida, there is a direct relationship between level of spinal lesion and severity of brain abnormalities, with higher spinal lesion associated with greater severity of brain abnormalities (Fletcher, Copeland, Fredrick, Blaser, Kramer, Northrup, et.al, 2005). Severity of brain abnormalities is inversely related to neurobehavioral outcomes. Patients with greater brain abnormalities and higher lesion levels have been noted to have poorer neurobehavioral outcomes and lower levels of functional independence (Fletcher, Copeland, Fredrick, Blaser, Kramer, Northrup, et.al, 2005).

Posttraumatic hydrocephalus. Hydrocephalus is a potentially severe (though uncommon) complication of traumatic brain injury (Menkes, 2000; Victor & Ropper, 2001). This posttraumatic hydrocephalus is usually caused by blood clots or adhesive basilar arachnoiditis that block the cerebral aqueducts and/or cause obstructions in the fourth ventricle (Menkes, 2000; Victor & Ropper, 2001). Patients with posttraumatic hydrocephalus initially present with headaches, vomiting, confusion, and lethargy. As pressure continues to build in the brain, patients begin to develop mental dullness, apathy, and psychomotor deficits (Menkes, 2000; Victor & Ropper, 2001). Traumatic brain injury patients may have other deficits directly associated with their brain injury (Ewing-Cobbs, Barnes, & Fletcher, 2003), but in all, these patients with posttraumatic hydrocephalus have many of the same cognitive symptoms as patients with hydrocephalus with different etiologies. In some cases the hydrocephalus resolves without medical intervention. In other cases ventricle shunting is needed to relieve intracranial pressure (Menkes, 2000; Victor & Ropper, 2001). When posttraumatic hydrocephalus patients are shunted, cognitive improvements have been observed (Silver & Chinarian, 1997).

Treatment of Hydrocephalus

Shunting. Shunting procedures, developed in the latter part of the twentieth century (Hirsch, 1992), were designed as a treatment for the increase in cerebrospinal fluid volume known as hydrocephalus. As mentioned above, hydrocephalus has a variety of etiologies and is characterized by an enlargement of the ventricles and in some cases the head itself (Del Bigio, 1993). Whatever the etiology, surgical intervention is often necessary and involves the placement of a shunt. The shunting procedure usually requires the patient to go under general anesthesia. During surgery a small hole is drilled through the top of the skull and a catheter is inserted through the cerebral cortex and into one of the lateral ventricles. The catheter is attached to a cap and valve that is positioned between the scalp and the outer skull. Tubing is tunneled subcutaneously from the valve to the abdomen. The tubing end is placed in the peritoneal cavity where cerebrospinal fluid is continuously drained (Verrees & Selman, 2004; Victor & Ropper, 2001).

In one year, a reported 5,574 patients in the United States were admitted into the hospital for shunt placement to treat hydrocephalus (Patwardhan & Nanda, 2005). Shunting is the standard treatment of hydrocephalus and when shunting is not implemented there is a subsequent high mortality rate ranging from 45% to 53%. With the implementation of a shunt, the mortality rate is greatly decreased from this high rate to a remarkably lower rate of 15% (Del Bigio, 1993).

Regardless of etiology, cognitive and intellectual functioning has been found to improve once hydrocephalus patients are shunted (Stambrook, Cardoso, Hawryluk, Erirkson, Piatek, & Sicz, 1988; Czepko, Danilewicz, Orlowiejska, & Szwabowska, 1999). Significant improvements in patient's attention, concentration, verbal and nonverbal memory, language and communication skills, and construction skills were all noted after being shunted (Stambrook, Cardoso, Hawryluk, Erirkson, Piatek, & Sicz, 1988). These findings were replicated in a more recent study examining the cognitive functioning of 95 hydrocephalus patients pre and post shunt placement surgery (Czepko, Danilewicz, Orlowiejska, & Szwabowska, 1999). This study revealed cognitive improvements in 81% of patients. The improvements noted in these patients were usually found in language functioning, working memory, and attention. In the remaining cases, 7% of the patients had no change in their cognitive functioning, and 12% were found to have a decline in functioning (Czepko, Danilewicz, Orlowiejska, & Szwabowska, 1999).

When patients are shunted, an increase in their performance on intelligence testing has been noted (Hirsch, 1992; Mataro, Antonia Poca, Sahuquillo, Cuxart, Iborra, et. al., 2005). One study found overall neurocognitive improvements in 52% of patients following shunt placement (Thomas, McGirt, Woodworth, Heidler, Rigamonti, Hillis, & Williams, 2005). Of these improved patients, the greatest improvements were seen in verbal memory and psychomotor speed. These findings support the results of a previous study by Mataro and colleagues (2000). In this study, shunted patients showed neuropsychological improvement in almost all areas, but the greatest improvements were found in verbal and visual memory, attention, and cognitive flexibility.

While shunting appears to improve cognitive functioning in the majority of patients, large improvements may not be experienced in patients with significantly lower baseline functioning. For example, one study found that patients who performed more than one standard deviation below the mean on verbal memory and immediate recall before shunt placement were less likely to show cognitive improvements after shunt placement (Tomas, McGirt, Woodworth, Heidler, Rigamonti, Hillis, & Williams, 2005). These results are important when attempting to predict cognitive functioning after shunt placement.

Neuropsychological Consequences of Hydrocephalus

Hydrocephalus and intelligence. Despite the many physical and cognitive impairments that patients with shunted hydrocephalus face, some research suggests the majority of them have global IQs in the normal range before and even after shunting (Fletcher, Francis, Thompson, Brookshire, Bonah, Landry, et. al., 1992; Hommet, Cottier, Billard, Perrier, Gillet, Toffol, et. al., 2002). Other research suggests shunted hydrocephalus patients may have IQs that are within the average range, but usually lower than those of normal controls (Fletcher, Francis, Thompson, Brookshire, Bonah, Landry, et. al., 1992; Friedrich, Lovejoy, Shaffer, & Shurtleff, 1991; Scott, Fletcher, Brookshire, Davidson, Landry, Bohan, et. al., 1998). Yet other research suggests that shunted patients have global IQs that are below average (Friedrich, Lovejoy, Shafer, & Shurtleff, 1991; Jacobs, 2001; Shafer, Friedrich, Shurtleff, & Wolf, 1985). One study, for example, revealed that patients with shunted hydrocephalus had IQ scores over twenty points lower than controls and lower than patients with arrested hydrocephalus (Scott, Fletcher, Brookshire, Davidson, Landry, Bohan, et. al., 1998).

The research appears united in stating that hydrocephalus patients do have some cognitive deficits. The increased intracranial pressure found in hydrocephalus can disrupt white matter and can distort development in the cortex. The corpus callosum is often stretched and there is a thinning of the cortical mantle throughout the brain (Del Bigio, 1993). This distortion of the cortex and other brain structures can lead to cognitive, neuropsychological, and motor impairments. A study examining children between the ages six and 11 with hydrocephalus who were shunted in their first year of life found those children to be globally compromised in cognitive skill. When compared to age and gender matched controls, the shunted patients displayed impairments in speed of processing, immediate registration of information, learning and memory, organization and high level language (Rani, Elisabeth, & Vicki, 2001). In this study, hydrocephalus patients displayed the greatest deficits on tasks that were ambiguous and multifaceted. In addition, shunted patients were noted to have a decline in IQ over time, suggesting a subsequent failure to acquire cognitive skills in the expected time frame (Rani, Elisabeth, & Vicki, 2001).

One factor that may cause patients with shunted hydrocephalus to have a lower IQ is the coincidental presence of nonverbal learning disorders (NVLD). Hydrocephalus is associated with abnormalities of the corpus callosum and it is postulated that NVLDs arise because of these abnormalities (Mataro, Matarin, Poca, Pueyo, Sahuquillo, Barrios, et al., 2007). Thinning of the corpus callosum and/or displacement of corpus callosum substructures may interfere with hemispheric communication and subsequently impair visuospatial skills (Mataro, Matarin, Poca, Pueyo, Sahuquillo, Barrios, et al., 2007). In addition, hydrocephalus can cause stretching and tearing of neuronal fibers which may damage the optic tracks or white matter tracks in the midbrain associated with the communication of visual information (Del Bigio, 1993).

The pattern of NVLD in shunted hydrocephalic patients is evident in the significant discrepancies that have been displayed between their verbal IQ and performance IQ on Wechsler's intelligence tests (Brookshire, et. al., 1995; Fletcher, Francis, Thompson, & Brookshire, 1992). While shunted patients are able to score in the average to above average range on the verbal sections of the IQ test, their scores are often below average on the nonverbal/performance section (Fletcher, Francis, Thompson, & Brookshire, 1992; Brookshire, et. al., 1995).

The influence of motor functioning, specifically, on global intelligence scores (Full Scale IQ; FSIQ) was examined in a study by Fobe, Rizzo, Silva, Da Silva, Teixeira, De Souza, and colleagues (1999). In this study, FSIQ and motor functioning were tested in forty-five children with hydrocephalus and spina bifida. Test results indicated that three patients (6.6%) had an FSIQ score > 110 (above the average range), 11 (24.4%) had a score between 100-110 (within the average to high average range), 8 (17.7%) had a score between 85-100 (within the low average to average range), 16 (35.5%) had a score between 70-85 and 7 (15.5%) had a score between 50-70 (within the moderately impaired to borderline impaired range). Statistical analysis revealed that FSIQ was directly correlated with motor functioning, with patients with better motor functioning having higher FSIQs. A study by Mazur, Aylward, Colliver, Stacey, and Menelaus (1988) also found IQ to be related to motor functioning. In their study of patients with spina bifida and hydrocephalus, IQ was found to be inversely related to motor functioning. These findings are supported by research done by Holler, Fennell, Crosson, Boggs, and Mickle (1995) which revealed that motor functioning is related to a patient's performance on tasks measuring verbal, communication, and learning skills.

Some researchers suggest that patients with shunted hydrocephalus do not have discrepancies between their verbal and performance scores, and that deficits are more global (Hommet, Billard, Barthez, Lourmiere, Santini, De Toffol, et. al., 1999; Scott, Fletcher, Brookshire, Davidson, Landry, Bohan, et. al., 1998; Jacobs, 2001). These studies found shunted hydrocephalus patients to have lower performance and verbal IQs, suggesting that poor motor skills pull down FSIQ scores (Fobe, Rizzo, Silva, Da Silva, Teixeira, De Souza, et. al., 1999; Mazur, Aylward, Colliver, Stacey, & Menelaus, 1988).

Clearly, there is a lot of conflicting research on the influence of hydrocephalus on IQ. It appears that the preponderance of research evidence suggests hydrocephalus patients have IQ scores that are in the low average range (that is, they fall below the mean of the general public). The degree to which motor functioning influences IQ scores is not fully understood. Impaired motor skill can account for lower performance IQ scores, but not lower verbal IQ scores. Furthermore, it cannot be assumed that lower performance scores are strictly the result of poor motor skills; in an academic setting, hydrocephalus patients have been noted to have difficulties in math computations, written expression (content) and reading comprehension (Barnes & Dennis, 1992; Wills, Holmbeck, Dillion, & Melone, 1990). The inconclusive findings highlight the need for more research.

Hydrocephalus and motor skills. Hydrocephalus is commonly associated with fine motor deficits (Thompson, Fletcher, Chapieski, Landry, Miner, & Bixby, 1991), as well gross motor problems in the lower extremities (Fletcher, Brookshire, Bohan, Bandt, & Davidson, 1995). Over half of patients with hydrocephalus related to spina bifida and Chiari malformation were found to have motor deficits (Kao, Yang, Wong, Cheng, Huang, Chen, et. al., 2001). Some researchers suggest that motoric problems are the result of psychomotor difficulties, mainly psychomotor retardation (Thompson, Fletcher, Chapieski, Landry, Miner, & Bixby, 1991).

A study comparing children with hydrocephalus, children with hydrocephalus and spina bifida, and a control group without hydrocephalus or spina bifida yielded valuable insight into the relationship between hydrocephalus and motor functioning (Muen & Bannister, 1997). Results from this study suggested that patients with spina bifida have weaker power in the small muscles of the hand, poorer fine motor control, and less coordination when compared to patients with hydrocephalus and no spina bifida and when compared to controls. There were no significant differences between controls and those with isolated hydrocephalus. This study found IQ and cerebral hemisphere pathology to be unrelated to motor control functioning within and between groups. In a similar study, patients with spina bifida and hydrocephalus were found to take significantly longer to complete hand functioning tasks than normal controls, and also performed below patients with hydrocephalus and no spina bifida (Mazur, et. al., 1988). In the patients with spina bifida and hydrocephalus, motor functioning was related to their spinal lesion level, and the number of shunt replacements. Thus, it may be inferred from these studies that motor dysfunction is a product of CNS damage and not related to hydrocephalus itself. The relationship between motor dysfunction and hydrocephalus, rather, seems to rest namely in the CNS damage associated with hydrocephalus and any complications associated with treatment (shunt placement, shunt infections, shunt malfunctions, shunt revisions).

Attention and Executive Functioning. Research has indicated that patients with hydrocephalus associated with spina bifida have problems with vigilance and persistence on cognitive tasks (Tew, Laurence, & Richards, 1980). Patients with hydrocephalus and spina bifida have also been notably more distractible than their non-hydrocephalic counterparts. Patients with hydrocephalus have been found to perform more poorly on measures of problem solving, attention, and selective attention than controls (Fletcher, Brookshire, Landry, Bohan, Davidson, Francis, et. al., 1996). In addition, this higher degree of distractibility is thought to reduce performance on receptive vocabulary measures (Horn, Lorch, Lorch, & Culatta, 1985). A more recent study using an extensive attention battery compared children with congenital hydrocephalus associated with spina bifida to children with attention deficit hyperactivity disorder (ADHD) (Brewer, Fletcher, Hiscock, & Davidson, 2001). The tests used in this study focused on attention systems moderated by posterior and anterior brain networks. The results indicated that children with congenital hydrocephalus performed worse on measures of sustained attention and divided attention than those with ADHD (Brewer, Fletcher, Hiscock, & Davidson, 2001). Patients with hydrocephalus associated with spina bifida have been found to have a higher incidence of ADHD than that found in the normal population (Burmeister, Hannay, Copeland, Fletcher, Boudousquie, & Dennis, 2005). However, the attentional problems found in hydrocephalus patients with spina bifida are more often marked by inattention instead of the impulsivity and hyperactivity type more commonly found in the

ADHD population (Burmeister, Hannay, Copeland, Fletcher, Boudousquie, & Dennis, 2005).

These deficits in attention appear to contribute to lower scores on intelligence measures, as the children with hydrocephalus performed more poorly on attentional measures, had lower general IQ, and had lower scores on both performance/nonverbal IQ (PIQ) and verbal IQ (VIQ) than children with ADHD. In congruence with previous research, VIQ scores of children with hydrocephalus were significantly higher than their PIQ scores (Fletcher, Francis, Thompson, & Brookshire, 1992; Brookshire, et. al., 1995).

In direct converse, research by Dise and Lohr (1998) suggests that IQ and attention are unrelated. In their study, all hydrocephalus patients, regardless of IQ, displayed significant impairments in mental flexibility, processing efficiency, conceptualization, or problems-solving abilities. Dise and Lohr (1998) argue that these neuropsychological deficits underlie lower IQs and academic performance in hydrocephalus patients. Furthermore, they suggest that motivational difficulties play a key role in the lower performance of hydrocephalus patients.

In all, the majority of research has found the IQ deficits in hydrocephalus patients to be related to attention and executive functioning. Dise and Lohr (1998) argue against the role of attention in lower IQ scores of hydrocephalus patients and assert that the lower IQ scores are related to dysfunction in other executive skills. Although these authors' findings contradict the previous research pertaining to attention and IQ scores, their findings concur with the literature regarding executive functioning and IQ.

Hydrocephalus and Memory. A 1995 study compared the memory functioning of patients with arrested hydrocephalus, patients with shunted hydrocephalus, and a control group. Results from this study revealed that patients with shunted hydrocephalus performed poorer on verbal memory tasks (list learning) than the other two groups (Yates, Enrile, Loss, Blumenstein, & Delis, 1995). The patients with shunted hydrocephalus performed more poorly in their rate of learning, delayed recall, and showed less evidence of a recency effect. The shunted hydrocephalus group performed as well as the other groups on measurements of recognition, interference, and cued recall. Interestingly, performance of the hydrocephalus group was not significantly different from the control group (Yates, Enrile, Loss, Blumenstein, & Delis, 1995). This suggests that the need for shunt placement and/or the actual placement of the shunt has a detrimental impact on memory. Subcortical white matter abnormalities in shunted patients may contribute to their difficulties in delayed memory and retrieval (Yeates, Enrile, Loss, Blumenstein, and Delis, 1995).

Similar results were found in a more recent study that measured both verbal and nonverbal memory (Scott, Fletcher, Brookshire, Davidson, Landry, Bohan, et. al., 1998). This study examined 157 patients with hydrocephalus, and a correlation was found between severity of hydrocephalus and the degree of memory impairments (Scott, Fletcher, Brookshire, Davidson, Landry, Bohan, et. al., 1998). When patients with shunted hydrocephalus were compared to patients with arrested hydrocephalus and a control group with no hydrocephalus, the patients with shunted hydrocephalus performed poorer on both verbal and nonverbal memory tasks than the other groups. The patients with arrested hydrocephalus performed poorer than controls, but their performances were inconsistent and not significantly different than controls. The authors stated that difficulties with encoding and retrieval may explain the poorer performance by the shunted hydrocephalus group (Scott, Fletcher, Brookshire, Davidson, Landry, Bohan, et. al., 1998).

A recent study by Vachha & Adams (2005) gives another hypothesis as to why patients with shunted hydrocephalus perform more poorly than controls on memory tasks. In their study, patients with shunted hydrocephalus performed more poorly on tests measuring memory and selective learning than patients without hydrocephalus. Patients with shunted hydrocephalus had significantly lower memory span scores on three separate learning trials. These lower memory scores were attributed to the ineffective strategies the shunted hydrocephalus patients reported using in the learning and memory tasks. The majority of shunted hydrocephalus patients reported trying to memorize all the words without placing them in semantic categories. The control group reported memorization based on semantic categories. To test if both groups were capable of organizing the words into categories, they were asked to categorize the words into two groups. Both groups categorized the words with 100 percent accuracy. This suggests that the hydrocephalus patients could place the words in semantic groups, but could not independently apply this strategy when trying to memorize the words. Thus, this study suggests the memory deficits found in shunted hydrocephalus patients are a product of poor memorization strategy, a problem not found in the control group.

Results from these studies suggest that the severity of hydrocephalus is an important factor related to memory functioning. In all three of these studies, patients with shunted hydrocephalus performed more poorly than patients with arrested hydrocephalus, non-shunted hydrocephalus, and controls. This evidence suggests that the need for shunting and/or the shunting process itself has a detrimental effect on memory functioning.

Hydrocephalus and visuospatial skills. Patients with congenital hydrocephalus associated with spina bifida (Chiari II malformation) were found to perform more poorly on visuospatial memory tests than those with noncongenital hydrocephalus associated with aqueduct stenosis (Hommet, Billard, Barthez, Lourmiere, Santini, De Toffol, et. al., 1999). When patients with spina bifida and shunted hydrocephalus were compared to patients with only spina bifida (no hydrocephalus), the shunted patients performed significantly worse. This deficit in intellectual abilities was directly related to their visuospatial abilities (Tew & Laurence, 1975). This phenomenon may be explained by the brain malformations associated with spina bifida and its accompanying Chiari II malformation. The brain malformations associated with Chiari II are more severe than those of patients with hydrocephalus caused by aqueduct stenosis (Menkes, 2000, Victor & Ropper, 2001).

Patients with spina bifida and hydrocephalus have been found to display severe deficits on measures of visual planning and visual sequencing (Snow, 1999). Their performance in these areas was significantly below that of controls and that of a learning disorder sample. However, patients with spina bifida and hydrocephalus were also found to display deficits in executive functioning. These patients showed extreme perseveration of responses, diminished skills in problems solving, and diminished abstraction abilities. Deficits in these areas would undoubtedly have a detrimental impact on other areas of cognition and likely pulled down the spina bifida patients' scores on the visuospatial tests.

Results from these studies all suggest that hydrocephalus is associated with visuospatial deficits. These deficits appear to be confounded if hydrocephalus is the result of spina bifida and the accompanying Chiari II malformation. MRI results from patients with spina bifida and hydrocephalus found visuospatial disturbances to be closely related to morphological characteristics of the lateral ventricles (Ito, Saijo, Araki, Tanaka, Tasaki, Cho, & Miyamoto, 1997). There appears to be an inverse relationship between the ratio of the posterior horns to the anterior horns (P:A) and visuospatial abilities (Ito, Saijo, Araki, Tanaka, Tasaki, Cho, & Miyamoto, 1997). The morphological changes found in patients with hydrocephalus and spina bifida appear to greatly affect their visuospatial skills. However, executive problems also appear to have a detrimental impact on visuospatial skills. More research is need to determine if executive problems and morphological changes have an additive effect, or if there is a large amount of shared variance.

The Impact of Shunt Infection and Revisions on Cognition. Patients with shunted hydrocephalus have been found to have IQs ranging from above average to significantly impaired (Fobe, Rizzo, Silva, Da Silva, Teixeira, De Souza, et. al., 1999). Some of the variation in IQ can be explained by the number of shunt infections and shunt revisions a patient has undergone. In North America, patients with shunted hydrocephalus have an infection rate averaging 8-10%. One of the standard treatments of shunt infection is a shunt revision. (Drake, Kestle, Milner, Cianalli, Boop, Piatt, et. al., 1998). A nationwide inpatient sample database revealed that in the year 2000 there were 5,574 patients admitted in to the hospital for a shunt surgery. Of these patients, 7.2% were admitted with a shunt infection (Patwardhan & Nanda, 2005).

Shunt infection is associated with fever, seizures, increased risk of future infection, and higher risk of future shunt malfunction. In addition, surgery is necessary to remove the infected shunt and replace it with a new one (Drake, Kestle, Milner, Cianalli, Boop, Piatt, et. al., 1998). For those patients who have experienced a shunt infection, a reduction in IQ has been noted as well as poorer school performance (Drake, Kestle, Milner, Cianalli, Boop, Piatt, et. al., 1998; Fobe, Rizzo, Silva, Da Silva, Teixeira, De Souza, et. al., 1999). Shunt infections are caused by bacteria that enter the cranium during the shunt placement surgery (Drake, Kestle, Milner, Cianalli, Boop, Piatt, et. al., 1998). Although little is known about the direct impact of shunt infection on cognition, other brain infections have been associated with specific cognitive declines (Koomen, Van Furth, Kraak, Grobbee, Roord, & Sennekens-Schinkel, 2004; Merkelbach, Sittinger, Schweizer, & Muller, 2000; Pentland, Anderson, & Wrennall, 2000; Schmidt, Heimann, Djukic, Mazurek, Fels, Wallesch, & Nau, 2006).

Patients that have suffered from bacterial meningitis have been noted to experience declines in short-term memory, verbal learning and memory, language, working memory, and executive function twelve years after their infection (Koomen, Van Furth, Kraak, Grobbee, Roord, & Sennekens-Schinkel, 2004; Merkelbach, Sittinger, Schweizer, & Muller, 2000; Pentland, Anderson, & Wrennall, 2000; Schmidt, Heimann, Djukic, Mazurek, Fels, Wallesch, & Nau, 2006). When compared to patients that had viral meningitis in the past one to twelve years, those with bacterial meningitis performed more poorly on tests measuring short-term and working memory, executive function, language, and verbal learning/memory (Schmidt, Heimann, Djukic, Mazurek, Fels, Wallesch, & Nau, 2006). Other studies have found that patients with a history of bacterial meningitis display psychomotor slowing and disturbances with concentration, visuoconstruction capacity, and memory (Merkelbach, Sittinger, Schweizer, & Muller, 2000; Pentland, Anderson, & Wrennall, 2000). The psychomotor slowing found in former bacterial meningitis patients may be related to difficulties with motor steadiness (Koomen, Van Furth, Kraak, Grobbee, Roord, & Sennekens-Schinkel, 2004). Children that suffered from bacterial meningitis before the age of eleven were found to display language deficits. These deficits are thought to be the results of delays in language development associated with bacterial meningitis (Pentland, Anderson, & Wrennall, 2000). Some have postulated that these delays in language development lead to ongoing difficulties in keeping up with peers in the later stages of language development (Baraff, Lee & Schriger, 1993).

Bacterial meningitis is comparable to shunt infections in that both are the result of bacterial infections in the brain (Drake, Kestle, Milner, Cianalli, Boop, Piatt, et. al., 1998; Schmidt, Heimann, Djukic, Mazurek, Fels, Wallesch, & Nau, 2006). Viral infections in the CNS have also been associated with cognitive declines; however these declines are not as significant as those found in bacterial infections (Schmidt, Heimann, Djukic, Mazurek, Fels, Wallesch, & Nau, 2006). The comparison of shunt infections to other bacterial infections found in the CNS appears more homogeneous than comparing shunt infections with viral CNS infections. It is postulated that shunt infections would produce cognitive dysfunction similar to that found in bacterial meningitis patients.

Shunt infections are only one reason for a shunt revision. Shunt revisions are often needed when a shunt malfunctions due to: tubing becomes kinked, tubing disconnecting from the shunt valve, damage to the shunt valve when stuck by something, or obstruction in the valve or tubing (Vernet, Camiche, & De Tribolte, 1990). Obstructions are most often caused when the proximal tip of the shunt is occluded with cell matter. In a study that followed 120 patients with infantile hydrocephalus, many of these patients had complications with their shunts and needed additional shunt operations. In all, 253 shunt revisions were completed on the 120 patients, a rate of 2.2 revisions per patient (Vernet, Camiche, & De Tribolte, 1990).

The patients that have undergone shunt replacement surgeries have been noted to have progressively lower IQs (Fobe, Rizzo, Silva, Da Silva, Teixeira, De Souza, et. al., 1999). Furthermore, patients that have undergone shunt revisions were found to have poorer life achievements as they pertain to independence, employment and use of a car. The number of shunt revisions a patient had undergone was directly related to their ability to achieve, especially when shunt revisions took place after age two (Hunt, Oakeshott, & Kerry, 1999).

While the aforementioned research suggests a link between the number of shunt revisions and a decline in cognitive abilities, other research denies the existence of this relationship. A study examining 46 shunted hydrocephalus patients found that cognitive and memory impairments were unrelated to the number of shunt revisions (Ralph, Moylan, Canady, & Simmoms, 2000). In addition, a long-term follow-up study on patients with congenital hydrocephalus found no correlation between the number of shunt revisions and psychological test results (Lumenta & Skotarczak, 1995). However, it is important to note that these studies did not administer neuropsychological batteries and did not address factors such as visuospatial skills, attention, memory, and fine motor functioning. In addition, these studies did not report whether their participants had ever contracted a shunt infection.

Conclusions

The preponderance of literature suggests that patients with hydrocephalus often display deficits in an array of neuropsychological areas. Research indicates the areas of attention, executive, visuospatial, memory and motor function are detrimentally impacted by hydrocephalus. The extent of these deficits tends to vary between individuals, but it is postulated that these differences are related to the number of shunt infections and shunt replacements. While overall intelligence appears to be within the average range, it is often below the mean. The need for shunt replacement and the correlating surgery appears to confound the deficits found in hydrocephalus patients. The deficits found in shunted patients appear to be global, but several studies suggest marked impairment in attention and executive functioning (Brewer, Fletcher, Hiscock, & Davidson, 2001; Burmeister, Hannay, Copeland, Fletcher, Boudousquie, & Dennis, 2005; Fletcher, et. al., 1996; Tew, Laurence, & Richards, 1980). In fact, several studies have suggested that poor attention and executive skill are responsible for shunted hydrocephalus patients' poorer performance in other functional areas, such as memory (Scott, et.al., 1998; Vachha & Adams, 2005) and visuospatial skills (Frank, Lazarus, & Nathoo, 2003; Snow, 1999). It is further speculated that these deficits in attention and executive functioning not only affect memory and visuospatial skills, but overall performance on measures of IQ as well. The performance section of the IQ test is time sensitive, requires problems solving, attention, and set shifting. Thus, it can be presumed that such deficits in attention and executive functioning will have detrimental effects on individual subtest scores and subsequently bring down overall performance and general IQ scores.

CNS infections appear to produce additional deficits in memory, motor skills, language, and executive functioning. The degree to which shunt infections and additional shunts impair the different areas of cognition is not fully understood. Further research is needed to understand the impact of not only shunting but of shunt infections on cognition. Current research addressing shunting and cognition has not determined if shunt infections cause impairments above and beyond that of shunt malfunction. Further research is needed to address the impact of shunt infection on cognition. Some research has noted a decline in cognitive functioning related to the number of shunt surgeries (Patwardhan & Nanda, 2005; Drake, Kestle, Milner, Cianalli, Boop, Piatt, et. al., 1998; Fobe, Rizzo, Silva, Da Silva, Teixeira, De Souza, et. al., 1999). However, these studies addressed general cognition and did not address the impact of shunt placement or shunt infection on specific neuropsychological functions (i.e., executive functions, attention, memory, visuospatial skills, and motor skills). Furthermore, previous studies have not addressed how patients with spina bifida and Chiari malformation are impacted by multiple shunts and shunt infections. The propensity of hydrocephalus in spina bifida provides a clinical sample for the analysis of multiple shunts and shunt infections on neuropsychological functioning. This clinical sample also allows the examination of how CNS disorders additionally impact outcomes.

Study objective and hypotheses

The objective of this study is to assess the impact of shunt revision and shunt infection on neuropsychological functioning in children with spina bifida. This study examined patients that have a shunt and history of shunt infection, patients with a shunt but no history of shunt infection, and patients without a shunt. It is important to note that all patients with a shunt infection have a history of at least one shunt revision. Patients with a shunt and not history of infection may have a shunt revision, but revisions were not related to shunt infections. When examining the factors related to shunt placement, only patients with shunts and no history of shunt infection were used (group 2). Group 1 (history of shunt and shunt infection) was only used to examine factors related to shunt infection.

It is hypothesized that:

1. Patients with spina bifida that have a shunt and experienced a shunt infection(s) (group 1) will perform poorer on tests measuring motor skills, attention, processing speed, language and verbal memory, than patients with spina bifida with a shunt but no history of shunt infection (group 2) and patients with spina bifida without a shunt (group 3).
2. IQ scores will be inversely related to the number of shunt placements a patient has undergone.
3. IQ scores will be inversely related to the number of shunt infections a patient has contracted.
4. Attention and executive functioning will moderate the relationship between shunt placement and cognitive test performance.

Methods

Participants

Given the high prevalence of hydrocephalus in patients with spina bifida, patients with spina bifida were examined in this study. Participants for this study were solicited from the waiting room in the Loma Linda University Spina Bifida clinic. This clinic serves approximately 500 patients. The clinic is open once a week and approximately 20 patients are seen each day the clinic is open. In all, 12 patients spina bifida with shunted hydrocephalus and a history of shunt infection(s) (group 1), 15 patients with spina bifida, shunted hydrocephalus, and no history of infection (group 2), and 17 patients with spina bifida and no shunts (group 3) were examined. Patients between the ages of six and 16 were selected. Inclusion criteria for group 1 (patients with spina bifida, shunted hydrocephalus and history of shunt infection) included: (1) prior placement of a vetriculoparitoneal (VP) shunt; (2) diagnosis of spina bifida; and (3) a functional mastery of the English language (being able to speak and read English fluently), and (4) history of shunt infection. Inclusion criteria for group 2 (patients with spina bifida, shunted hydrocephalus and no history of shunt infection) included: (1) prior placement of a VP shunt; (2) diagnosis of spina bifida; (3) a functional mastery of the English language. Inclusion criteria for group 3 (patients with spina bifida and no shunt) included: (1) diagnosis of spina bifida; (2) no history of shunt placement and (3) a functional mastery of the English language.

Exclusion criteria for groups 1 and 2 included: (1) evidence of shunt malfunction and/or infection within 90 days prior to testing; (2) physical disabilities of movement that may compromise standardization of testing; (3) the presence of seizure or any other neurological illness or condition not directly related to spina bifida or hydrocephalus. Exclusion criteria for group 3 include: (1) history of ventricular shunting; (2) history of CNS infection; (3) any history of neurologic illness or condition not directly related to spina bifida.

Measurements

Shunt placements and infections. Patients and/or caretakers were asked about the number of shunt surgeries the participants had undergone and the number of shunt infections they had experienced. Gathered information was corroborated with available medical records.

Neuropsychological measurements. The measures used in this study assessed general intelligence and various domains of neuropsychological function, namely: general intelligence, verbal memory, nonverbal/visual memory, attention, information processing speed, visuospatial skills, executive functions and motor functioning. A description of the measures used to assess these domains is provided below.

Intelligence. General intelligence was assessed with the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV). The WISC-IV was normed on a sample of children between the ages of 6 and 16 that is comparable to U.S. census data. The WISC-IV yields a Full Scale Intelligence Quotient (FSIQ) and four index (composite) scores. The four index scores are the Verbal Comprehension Index (VCI), the Perceptual Reasoning Index (PRI), the Working Memory Index (WMI), and the Processing Speed Index (PSI). These indices can be interpreted individually, and/or can be combined statistically to make the FSIQ. The FSIQ and all indices are based on a mean of 100 and a standard deviation of 15.

Verbal memory. The California Verbal Learning Test-Children's Version (CVLT-C) was used to assess verbal memory of patients between the ages of 6 and 16. The CVLT-C assesses one's immediate and delayed recall of a series of words that are semantically related. Examinees have multiple trials to learn a series of words, and memory of these words is tested immediately after each trial, and after a 20-minute delay. The CVLT-C yields insight into examinees' verbal memory, learning rate, learning strategies (i.e., semantic clustering), and retention of information over short and long delays. However, for the purpose of this study and for comparing results to the visual memory test (Rey Complex Figure Test), only the CVLT-C short delay free recall and the 20-minute long delay free recall scores were used as dependent variables. These scores are based on age appropriate norms and converted into z-scores (Delis, Kramer, Kaplan, & Ober, 2000, norms).

Nonverbal memory. The Rey Complex Figure Test (RCFT) and Recognition Trial (Meyers & Meyers, 1995) was used to assess nonverbal/visual memory. This test requires the examinee to copy a complex figure design, and then reproduce the figure from memory three minutes later. Examinees are also required to reproduce the figure from memory 30 minutes after that. After the examinee completes the 30-minute reproduction of the figure, the examinee is shown multiple smaller figures and asked to identify (recognize) which of the smaller figures was part of the large original complex figure. This test provides insight into the examinee's nonverbal/visual memory and also yields information concerning their planning, organizational, perceptual, and motor functioning (Spreen & Strauss, 1998). This test was normed on individuals between the ages of 6 and 89, and examinees' copy and long delay free recall scores were compared to age-appropriate and education-appropriate norms in order to calculate z-scores (norms from Kolb & Whishaw, 1985).

Attention. Attention was assessed with the Digit Span subtest found in the WISC-IV. This subtest requires the examinee to immediately repeat increasingly longer strings of numbers. This subtest yields an overall scaled score with a mean of 10 and a standard deviation of 3. Examinees' Digit Span total scores were used as a dependent variable in this study, and scores were compared to age-appropriate norms.

Divided attention was assessed using the Letter-Number Sequencing subtest found in the WISC-IV. In this measure, increasingly longer strings of number and letters are read to the examinee and the examinee is required to repeat back the number and letters in numerical and alphabetical order. As with other WISC-IV subtests, this measure yields a scaled score based on a mean of 10 and a standard deviation of 3. Examinees' Letter-Number Sequencing total score was used as a dependent variable in this study, and scores were compared to age-appropriate norms.

Information processing speed. Information processing speed was measured with the Digit Symbol Coding and Symbol Search subtests found in the WISC-IV. The Digit Symbol Coding subtest requires the examinee to fill in empty squares with the corresponding symbol based on a symbol key as quickly as possible within a 120-second time limit. On the Symbol Search subtest the examinee is required to scan two sets of symbols and indicate whether the target symbol is in the second set of symbols. The examinee is to do so as quickly as possible within a 120-second time limit. Like other

WISC-IV subtests, these subtests yield a scaled score based on a mean of 10 and a standard deviation of 3. The Digit Symbol Coding subtest total score and the Symbol Search total score were used as dependent variables, and scores were compared to appropriate age-appropriate norms. A Processing Speed Index (PSI) is derived using the scores from Symbol Search and Digit Symbol Coding. The PSI has a mean of 100 and a standard deviation of 15.

Information processing speed was assessed with Trials A from the Trail Making Test (TMT). In this test the examinee is required to draw a line from one circled number to another, in numerical order. This is a timed test, and the examinee's time to complete this test was used as a dependent variable, and was compared to age appropriate normed data so that z-scores could be calculated (Anderson et al., 1997 norms).

Visuospatial skills. Visuospatial skills were assessed by the Block Design and Picture Completion subtests of the WISC-IV, and copy portion of the RCFT. The Block Design subtest requires the examinee to assemble increasingly more complex block designs using pictures or block models as a reference. The Picture Completion subtest requires the examinee to identify important but subtle objects missing in a picture. As with other WISC-IV subtests, these subtests yield a scaled score based on mean of 10 and a standard deviation of 3. The total score on each subtest was used as a dependent variable in this study. As discussed above, the RCFT copy condition requires the examinee to copy a complex picture, and scores are compared to age appropriate norms and z-scores are obtained (norms from Kolb & Whishaw, 1985). The total copy score was used as the dependent variable for this purpose.

Executive function. Executive function was assessed with Trails B from the Trail Making Test (TMT) and the Wisconsin Card Sorting Task 64 (WCST). Trails B requires the examinee to connect a series of numbers and letters in alternating (number then letter) sequential order. This is a timed test, and the examinee's time to complete this test was used as a dependent variable, and was compared to age appropriate normed data so that z-scores could be calculated (Anderson et al., 1997 norms).

The WCST has normative data on individuals from 6 through 89 years of age. The WCST consists of four stimulus cards and 64 response cards. The examinee is instructed to match each consecutive card from the response deck to one of the four stimulus cards. The examinee is not told how to match the cards, but is told whether each match response was correct or incorrect. Once the examinee has correctly matched a specific number of response cards, the matching principle is changed without notification to the examinee. The examinee is to use the examiner's feedback ("right" or "wrong") to determine the new matching principle. There are three matching principles, and principles are changed once the examinee correctly matches 10 consecutive cards. This test is thought to assess abstract reasoning abilities, ability to shift cognitive set, ability to learn from experience, and impulse control. The number of cards used to complete the three categories two times, the number of cards used to complete the first category, and the number of times the examinee failed to maintain set were used as dependent variables. Scores were compared to age appropriate norms and z-scores were obtained (Paniak, et. al, 1996, norms).

Motor. Motor functioning was assessed with the Grooved Pegboard test. The Grooved Pegboard test requires the examinee to place key-like pegs into holes using only their dominant hand, and then using only their non-dominant hand. Examinees are scored based on their time to complete the test using each hand, and scores are compared to age appropriate norms and z-scores are obtained (Rosselli et al., 2001, norms).

Procedure

Consent. The patients and their parent or guardian signed a written consent and assent to participate in this study. Consenting patients from the Loma Linda University spina bifida clinic who met study criteria were examined. These patients were given a neuropsychological assessment battery consisting of the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV), the Trail Making Test (TMT, parts A and B), Rey Complex Figure Test (RCFT) and Recognition Trial, California Verbal Learning Test for Children (CVLT-C), Wisconsin Card Sorting Test (WCST), and Grooved Pegboard test. Selected subtests from the WISC-IV were utilized to assess additional functions as described above. Patients' test data were compared to published normative data to obtain related z-scores.

Statistical analyses. Descriptive statistics were used to obtain demographic data for the collective group and individual groups (e.g., gender, age, etc.). Chi-square was used to determine if there were any demographic differences between groups. For hypothesis one, ANOVA was used to determine if patients with shunt infections (group 1) differed from the other two groups on measures of cognitive functioning. Specifically, ANOVA was used to determine if a history of a shunt infection(s) was associated with differences in test scores between the three groups. For hypothesis two, correlation analysis was used to determine if global cognitive deficits were related to the number of shunts (without history of infection) a patient has received. In addition, ANOVA was used to determine if group 2 and group 3 differed on measures of intelligence. For hypothesis three, correlation analysis was used to determine if global cognitive deficits were related to the number of shunt infections a patient has experienced. In addition, ANOVA was used to analyze differences between group 1 and group 3 on measures of intelligence. For hypothesis four, ANCOVA was used to determine if the relationship between number of shunts and global functioning was mediated by attention and executive function test scores. Specifically, ANCOVA was used to determine if the relationship between shunts and global functioning would change when the variance associated with the Digit Span forward score, Letter Number Sequencing total score, and WCST categories was removed.

Patients with scores that were more than three standard deviations above or below the group mean, and scores that were more than one standard deviation above or below the other scores in their respected domains were considered outliers. Although there was a wide range of scores within each domain, no scores in this study were considered outliers.

Confidentiality of data. All patient information was held confidential and available only to those directly involved in the study. Patients were given a subject number and only their subject number was placed on test data. All patient identifying information was kept separate from test data. Patients were provided with a summary of their test results pertaining to cognitive strengths and weaknesses. Patients were not given their IQ scores or percentile rankings of cognitive functioning.

Results

Subjects

A total of 44 patients were tested for this study. Of these 44 patients, 23 were female and 21 male. The mean age was 11 years (SD = 2.76), and ages ranged from 7 to 16 years. The mean number of shunts these patients received was 1.09 (SD = 1.56) with a median of 1.0. The mean number of shunt infections for these patients was .26 (SD = .66), with a median of 1.

Chi square revealed no significant differences between groups 1, 2 and 3 with regards to gender or age. See Table 1 for demographic characteristics for the entire sample and by group.

Test Results- Collective Sample

For the collective group of 44 patients, the mean FSIQ was below average, the VCI was below average, the PRI was low average, the WMI was low average, and the PSI was below average. See Tables 2 and 3 for complete test results. Due to the fact that all patients scored two or more standard deviations below the mean on TMT Trails A and B, data from these tests were not used in analyses.

Hypothesis I

Hypothesis one stated that patients that have experienced shunt infections (group 1) will perform poorer on tests measuring motor skills, attention, processing speed, language and verbal memory than patients without a history of shunt infection (group 2) and patients with no shunt (group 3). In addition, the differences in motor skills, attention, processing speed, language and verbal memory between groups 2 and 3 were examined to determine if a shunt placement, even without infection, could impact cognitive performance. ANOVA revealed that patients with a history of shunts but no infection and patients with a history of shunts with shunt infection did not differ from the no shunt group on tests measuring dominant (Peg Board dominant hand) and non-dominant (Peg Board non dominant hand) motor functioning (F (1, 32) = 3.02, p >.05, CI_{95} = 2.77, 2.82 ; F (1, 27) = 4.27, p > .05, CI_{95} = 2.77, 2.82 respectively). ANOVA also revealed no significant differences between the three groups on measures of attention (Digit Span) (F (2, 44) = 4.48, p > .05, CI_{95} = 1.32, 2.02; language (VCI) (F (2, 44) = 4.26, p > .05, CI_{95} = 2.87, 3.66; or processing speed (PSI) (F (2, 44) = 3.49, p > .05, CI_{95} = 1.22, 1.71).

Significant differences were found when ANOVA was used to determine group differences on tests of memory. Specifically, patients with shunts but no infection performed significantly below the no shunt group on tests measuring both verbal and nonverbal long term recall [CVLT-C long delay: F (1, 32) = 3.98, p = .019, CI_{95} = 5.12, 5.73, and RCFT long delay: F (1, 32) = 4.13, p = .015, CI_{95} = 4.32, 4.11 respectively]. Patients with shunts and a history of shunt infection also performed significantly below the no shunt group on tests measuring both verbal and nonverbal memory [CVLT-C short delay free recall: F (1, 29) = 4.61, p = .011, CI_{95} = 3.32, 4.27; CVLT-C long delay free recall: F (1, 29) = 4.79, p = .012, CI_{95} = 4.76, 5.18, RCFT long delay free recall: F (1, 29) = 4.27, p = .013, CI_{95} = 4.53, 4.97]. There was no significant difference between the shunt but no infection and shunt with infection groups on the remaining tests of memory

[CVLT-C long delay: F (1, 32) = 6.11, p = .324, CI_{95} = 2.21, 2.87; CVLT-C short delay: F (1, 32) = 6.07, p = .332, CI_{95} =2.47, 3.16; and RCFT long delay: F (1, 32) = 7.16, p = .441, CI_{95} = 2.01, 2.87, respectively]. In addition, number of shunts was significantly correlated with all scores on verbal and nonverbal memory tests (see Table 4).

Hypothesis II

Hypothesis two stated that IQ would be inversely related to the number of shunt placements a patient has undergone. Thus, this hypothesis was explored within group 2 only, as these individuals had variability in the number of shunt placements. Data analysis revealed that IQ was inversely related to the number of shunts a patient has received. Specifically, ANOVA revealed that those in the shunt-no infection group performed significantly lower than those in the no shunt group on FSIQ, F (1, 32) = 6.71, $p < .01$, CI_{95} = 5. 32, 5.97; Perceptual Reasoning Index (PRI), F (1, 32) = 3.83, $p < .05$, CI_{95} = 5.11, 5.42; and Working Memory Index (WMI), F (1, 32) = 3.85, $p < .05$, CI_{95} = 4.97, 5.13. Those in the shunt no infection group did not perform significantly different on the Verbal Comprehension Index (VCI), F (1, 32) = 1.27, $p > .05$, CI_{95} = 1.72, 2.13, when compared to those with no history of shunt placement. In addition, number of shunts was significantly correlated with FSIQ, PRI, PSI and WMI (see Table 5).

Hypothesis III

It was hypothesized that IQ scores will be inversely related to the number of shunt infections a patient has experienced (FSIQ, VCI, PRI, and WMI). Correlation analysis revealed that the number of shunt infections was not significantly correlated with IQ scores (see Table 6). ANOVA revealed significant differences existed between those in the shunt and infection group and those in the no shunt group in relation to scores on the FSIQ, $F\ (1, 29) = 5.86, p < .01, CI_{95} = 3.22, 3.44$; Perceptual Reasoning Index (PRI), $F\ (1, 29) = 3.84, p < .05, CI_{95} = 2.98, 3.11$; and Working Memory Index (WMI), $F\ (1, 29) = 3.85, p < .05, CI_{95} = 2.\ 76, 3.00$. Those in the shunt no infection group did not perform significantly different on the Verbal Comprehension Index (VCI), $F\ (1, 29) = 1.93, p > .05, CI_{95} = 1.98, 2.03$; when compared to those with no history of shunt placement.

Hypothesis IV

It was hypothesized that attention and executive functioning would mediate the relationship between shunt placements and shunt infections and cognitive deficits. As noted above, ANOVA revealed significant differences between those in the shunt group with no infection and those in the no shunt group in relation to scores on the FSIQ, $F\ (1, 29) = 5.86, p < .01, CI_{95} = 3.22, 3.44$; Perceptual Reasoning Index (PRI), $F\ (1, 29) = 3.84, p < .05, CI_{95} = 2.98, 3.11$; and Working Memory Index (WMI), $F\ (1, 29) = 3.85, p < .05, CI_{95} = 2.76, 3.00$. When the variance associated with attention and executive functioning (Digit Span, Letter Number Sequencing, and WCST categories completed) were removed, ANCOVA analysis revealed that those with a shunt did not significantly differ from the no shunt group in their performances on the PRI $F\ (1, 32) = 1.87, p > .05, CI_{95} = 1.12, 1.47$. However, significant differences still existed on the FSIQ, $F\ (1, 32) = 4.99, p < .05, CI_{95} = 3.22, 3.44$, and WMI, $F\ (1, 32) = 2.99, p < .05, CI_{95} = 2.\ 76, 3.00$. Patients with shunts performed significantly below the no shunt group on all measures that had a strong visual component (see Table 7). Also, correlation analysis revealed that the number of shunts was significantly correlated with all measures that had a strong visual component (see Table 8).

Those with a history of shunt infection did not significantly differ from the no-shunt group on scores related to FSIQ, VCI, PRI, WMI, and executive functioning, F (1, 29) = $p > .05$. This remained true even after the variance associated with attention and executive functioning (Digit Span, Letter Number Sequencing and WCST categories completed) was removed F (1, 29) = $p > .05$.

Discussion

The aim of this study was to identify the neuropsychological symptoms associated with multiple shunts and shunt infections in patients with hydrocephalus and spina bifida. Previous research has found a relationship between patients with a shunt and declines in intellectual functioning. However, prior research has not addressed the influence multiple shunts have on neuropsychological functioning. Furthermore, prior research has not examined how the different areas of cognition are influencing the intellectual declines found in shunted patients. Prior research has also failed to address how shunt infections are related to the cognitive functioning of spina bifida patients. This study examined the neuropsychological profiles of three groups of spina bifida patients. The first group had a history of shunt placement and shunt infection. The second group had a history of shunt placement but no history of shunt infection, and the third group had no history of shunt placement or shunt infection. These groups were compared in regards to their general intellectual functioning, attention, information processing speed, visual and verbal memory, motor, language, and executive functioning. This study addressed four hypotheses:

1. Patients with spina bifida that have a shunt and experienced a shunt infection(s) (group 1) will perform poorer on tests measuring motor skills, attention, processing speed, language and verbal memory, than patients with spina bifida with a shunt but no history of shunt infection (group 2) and patients with spina bifida without a shunt(group 3).

2. IQ scores will be inversely related to the number of shunt placements a patient has undergone.

3. IQ scores will be inversely related to the number of shunt infections a patient has contracted.

4. Attention and executive functioning will mediate the relationship between shunt placements and cognitive test performance.

As a whole, patients in this study displayed IQ scores that were below that found in previous studies (Fletcher, Francis, Thompson, Brookshire, Bonah, Landry, et. al., 1992; Hommet, Cottier, Billard, Perrier, Gillet, Toffol, et. al., 2002). This may be due to the fact that patients were not excluded from the study for having IQ scores below70, while other studies often excluded patients with IQ scores below 70. In addition, previous studies did not evaluate patients who spoke English as a Second Language (ESL), and almost half of the patients in this study were ESL (patients were determined ESL if a language other than English was learned first and if a language other than English was spoken primarily in the home).

Another factor that may have contributed to the lower IQ scores in this study is the manner in which patients were recruited. In this study patients were offered free neuropsychological testing for participating in this study. This may have encouraged patients with a higher degree of impairment to participate in the study, while patients with less severe impairments may have been less inclined to participate.

Results from this study revealed that patients in all three groups performed significantly below norms on measures of fine motor control. It is important to note that all (including the no shunt group) performed below age appropriate norms, regardless of their shunting or infection status. This suggests that shunting and shunt infections do not significantly influence the fine motor skills of hydrocephalus patients. All patients in this study had spina bifida and the below average motoric functioning is likely related to the physical malformations associated with spina bifida. Previous studies have suggested that fine motor difficulties in this population are related to weaker power in the small muscles of the hand, poorer fine motor control, and less coordination (Muen & Bannister, 1997). The coordination difficulties found in these patients are likely due to the cerebellar and basal ganglia malformations of spina bifida (Victor & Ropper, 2001). However, it is important to note that although no significant differences were found between the three groups on tests of fine motor control, groups 1 and 2 performed more than one z-score below group 3. This difference was not significantly different, but may be clinically significant. Groups 1 and 2 did perform more than one standard deviation below group 3, and the low *N* in this study may have prevented this finding from reaching a statistically significant level.

Patients with shunts and no history of shunt infection and patients with shunts and a history of infection performed significantly below the no shunt group on measures of verbal and nonverbal memory. Patients with a history of shunt infection also performed significantly below the no shunt group of measures of verbal and nonverbal memory. However, the shunt infection group did not significantly differ from the shunt group on memory tasks. Analysis of variance revealed that the differences between the shunt infection group and no shunt group were related to number of shunts, not shunt infection. Thus, number of shunts, not shunt infection, is the significant predictor of memory performance. Previous research has suggested that memory difficulties found in hydrocephalus patients are likely related to difficulties with encoding and retrieval (Scott, Fletcher, Brookshire, Davidson, Landry, Bohan, et. al., 1998). The shunted hydrocephalus patients in this study also appeared to have difficulties in encoding information, but did not appear to have retrieval problems. On the CVLT-C, for example, most patients had difficulties encoding the word list, but were able to retrieve the small amount of information they encoded (that is, their retention was good). These difficulties were more apparent in patients with a history of more than one shunt.

Although it was hypothesized that there would be group differences on attention, processing speed, and language scores, data analysis found no significant group differences in these domains. Spina bifida patients have been noted to have difficulties with inattention (Burmeister, Hannay, Copeland, Fletcher, Boudousquie, & Dennis, 2005), vigilance and persistence on cognitive tasks (Tew, Laurence, & Richards, 1980). Given that there were no significant group differences in these areas, it is likely that attention difficulties are related to spina bifida, not hydrocephalus or shunting.

Multiple shunts were significantly related to greater deficits in cognitive functioning. There was no significant relationship found between shunt infections and deficits in cognition. Patients with no history of shunt placement had a mean FSIQ that was in the average range, but was several points below the mean of the general population. Patients with a history of shunt placement had a mean FSIQ that was significantly below that of the no shunt group and age appropriate norms. A significant relationship was found between the number of shunt placements and deficits in FSIQ. Seeing that shunt infections did significantly account for the lower FSIQ scores, some other process related to the need for shunt replacement or the replacement itself must be responsible for the FSIQ decrements after shunt replacement. When a shunt malfunctions the patients reverts back to their hydrocephalic state. The longer the patient goes without a working shunt the more CSF accumulates in the ventricles and the greater the intracranial pressure (Fletcher & Levin, 1988; Wills, 1993). This increase in intracranial pressure may cause additional damage and/or displacement of brain structures, and may be responsible for the greater deficits in cognition found after a malfunction. When patients experience a shunt infection, the shunt usually continues to work even though there is active infection in the CSF. Although the presence of infection in the brain may cause damage to brain tissue, it appears relatively insignificant when compared to the damage caused by excessive intracranial pressure (Fletcher & Levin, 1988; Wills, 1993). However, the relatively low functioning of the patients with shunt infections may have prevented statistical analysis from detecting deficits associated with shunt infections.

It was hypothesized that attention and executive functioning would mediate the relationship between shunt placements/shunt infections and cognitive deficit. Results from this study found attention and executive functioning to mediate the relationship between performances on perceptual reasoning tasks and shunt replacements. Attention and executive functioning did not mediate the relationship between shunt replacements and any other factors. Difficulties with perceptual reasoning have been previously observed in patients with hydrocephalus, and is thought to be largely related to visuospatial difficulties (Hommet, Billard, Barthez, Lourmiere, Santini, De Toffol, et. al., 1999; Tew & Laurence, 1975). Results from this study suggest that these visuospatial difficulties found in hydrocephalus patients influence their performance on measures of intelligence (see Table 6). There was a direct correlation between IQ and performance on visuospatial tasks (Block Design, Picture Concepts, Matrix Reasoning, Picture Completion). This study found visuospatial deficits to be significantly related to shunt placement and shunt placements, with visuospatial deficits becoming compounded with each additional shunt replacement. Thus, with each shunt replacement there is an expected deficit in visuospatial skills and a subsequent deficits in performance on IQ tests due to IQ subtest that are visually based.

It is postulated that the deficits in executive functioning and visuospatial skills are related to communication disruptions between the brain structures of hydrocephalus patients. Abnormalities of the corpus callosum likely create communication difficulties between hemispheres (Mataro, Matarin, Poca, Pueyo, Sahuquillo, Barrios, et al. 2007). Furthermore, disruptions in white matter tracts (Del Bigio, 1993) may interfere with the way the frontal lobe communicates with the rest of the brain. The perception, reception, and interpretation of visual information requires significantly more white matter tracts than that used to process auditory information (Victor & Ropper, 2001). The compression effects of hydrocephalus can cause disruptions in myelination and cause thinning of the posterior brain regions used to process visual information (Fletcher & Levin, 1988; Wills, 1993). Seeing that executive functioning is related to visuospatial skills, disruptions in executive functioning pathways will also adversely affect visuospatial skills. Furthermore, executive and visuospatial pathways require communication between multiple lobes and utilize more white matter than auditory processes; it is logical that more deficit would appear in visuospatial skills, rather than auditory and language skill, in hydrocephalus patients.

In all, patients with a history of shunt infection did not significantly differ from patients in the shunt group without infection. Patients with a history of shunt infection usually experienced more shunt replacements and subsequently had lower FSIQ, PRI, and memory scores. The lower FSIQ scores found in multiple shunt patients is likely related to deficits in visuospatial skills. Multiple shunts also appear to be related to deficits in both verbal and nonverbal memory.

Study Limitations

This study had a relatively small *N* for each group. A larger *N* would have given statistical analyses more power, and would have made results more generalizable. If this study had more power in the statistical analyses, some of the analyses (i.e., fine motor control) may have reached significant levels. There was a great deal of inter-group variability on test scores, and a larger *N* would likely reduce this variability. This study also did not record the area in the brain in which shunts were placed. Where a shunt is placed and replaced may be variable and dependent upon individual patient characteristics and circumstances (e.g., integrity of the previous placement location), and thus may have an effect on cognition. In addition, this study had a relatively large population of ESL patients (ESL was determined by parental report indicating that the patient's first learned language was not English). Of the 44 patients in this study, 19 of them spoke English as a second language. Chi-square revealed that group 1 (history of shunt placement and no infection) (8 ESL patients) and Group 2 (history of shunt placement and shunt infection) (7 ESL patients) contained significantly more ESL patients than Group 3 (no history of shunt placement) (4 ESL patients) $p < .05$. These patients performed differently on some of the measures used and subsequently increased variability of test scores. Due to the mixture of ESL and non-ESL patients, the test results from this study cannot be generalized as well. When comparing ESL and non-ESL patients, ESLS patients displayed significantly lower IQ scores. As a whole, ESL patients performed significantly below non-ESL patients on the Full Scale Intelligence Quotient, Verbal Comprehension Index, and RCFT delay. Some of the ESL patients displayed a significant difference between their Verbal Comprehension and Perceptual Reasoning Indices. ESL patients performed significantly above non-ESL patients on the RCFT copy, CVLT-C Delay and Grooved Pegboard (see Table 9). It is important to note that the measure of ESL was not standardized and therefore may have resulted in some misclassifications. This may limit the interpretation of these results.

This study also used a relatively small age range, and thus the impact of shunt placements in different age groups could not be examined.

Future Directions

Future studies should address why multiple shunting adversely impacts performances on memory and visuospatial tasks. This study noted that some cognitive deficits were due to factors related to spina bifida. Future studies should address what is underlying the deficits found in spina bifida patients. The use of neuroimaging may be beneficial in addressing this question. It may also be beneficial to compare shunted patients with other patients that have experienced significant surgeries and hospitals stays in early childhood. Furthermore, a larger *N* and more diverse age group would make findings more generalizable. The small *N* in this study appeared to lower the power of the statistical analyses and subsequently made it more difficult to obtain significant results. It would also be beneficial to examine ESL and non-ESL patients separately. Finally, future studies should address how English as a second language may influence cognitive functioning in this population.

Study Significance

This study produced evidence regarding the adverse impact multiple shunts have on memory, visuospatial skills, and intelligence. This information may prove valuable in the treatment and management of shunted hydrocephalus patients, and help with the understanding of the neurobiology of spina bifida patients. This information may prove valuable in the development of Individual Education Programs for school aged patients. Shunted patients will likely need additional assistance on tasks that require memory and visuospatial skills. Educational programs should be aware of these difficulties and help individuals develop appropriate compensatory strategies. It is important to take efforts to avoided shunt infections and the associated shunt revisions. While CNS infections have been found to have a detrimental impact CNS tissue, this study found shunt infection was not significantly related to deficits in neuropsychological functioning. However, the number of shunt placements a patient has received was found to be significantly related to deficits in neuropsychological functioning. It is important to instruct patients and their families to take efforts to preserve the integrity of the shunt, to avoid the need for shunt replacement.

References

Barnes, M. & Dennis, M. (1992). Reading in children adolescents after early onset hydrocephalus and in normally developing age peers: Phonological analysis, work recognition and passage comprehension skills. *Journal of Pediatric Psychology, 17,* 445-466.

Bech, R.A., Waldemar, G., Gjerris, F., Klinken, L., & Juhler, M. (1999). Shunting effects in patients with idiopathic normal pressure hydrocephalus; correlation with cerebral and leptomeningeal biopsy findings. *Acta Neurochir, 141,* 633-639.

Baraff, L.J., Lee, S.I., & Schriger, D.L. (1993). Outcome of bacterial meningitis in children: A meta-analysis. *Pediatric Infectious Diseases, 12,* 389-394.

Brewer, V.R., Fletcher, J.M., Hiscock, M., & Davidson, K.C. (2001). Attention processes in children with shunted hydrocephalus versus attention deficit-hyperactivity disorder. *Neuropsychology, 15,* 185-198.

Brookshire, B., Fletcher, J.M., Bonal, T.P., Landry, S.H., et. al. (1995). Verbal and nonverbal skill discrepancy in hydrocephalic children: A five-year longitudinal follow-up. *Journal of Pediatric Psychology, 20*, 785-800.

Burmeister, R., Hannay, H.J., Copeland, K., Fletcher, J.M., Boudousquie, A., & Dennis, M. (2005). Attention problems and executive functions in children with spina bifida and hydrocephalus. *Developmental Cognitive Child Neuropsychology, 11,* 265-283.

CZepko, R., Danilewicz, B., Orlowiejska, M., & Szwabowska, D. (1999). The influence of shunt surgery on the improvement of cognitive disorders in hydrocephalic patients. *Przegl Lek, 56*, 489-493.

Del Bigio, M. R. (1993). Neuropathological changes caused by hydrocephalus. *Acta Neuropathologica, 85*: 573-585.

Dise, J.E. & Lohr, M.E. (1998). Examination of deficits in conceptual reasoning abilities associated with spina bifida. *American Journal of Physical Medical Rehabilitation, 77,*247-251.

Drake,J.M., Kestle, J.R., Milner, R., Cianalli, G., Boop, F., Piatt, J., Haines, S., Schiff, S., Cochrane, P., Steinbok, P., & MacNeil, N. (1998). Randomized trail of cerebrospinal fluid shunt valve design in pediatric hydrocephalus. *Neurosurgery, 43,* 294-303.

Erickson, K. (2001). Performance of patients shunted in childhood for "normal pressure" hydrocephalus on neuropsychological tests of attention and emotion. *The Sciences & Engineering, 61*, 4438.

Fletcher, J.M., Francis, D.J., Thompson, N.M., Brookshire, B.L., Bonah, T.P., Landry, S.H., et. al. (1992). Verbal and nonverbal discrepancies in hydrocephalic children. *Journal of Clinical and Experimental Neuropsychology, 14,* 593-609.

Fletcher, J. M., Brookshire, B. L., Bohan, T. P., Bandt, M. E., & Davidson, K. C. (1995). Early hydrocephalus. In Rourke, B. P. (ed)., *Syndrome of Nonverbal Learning Disabilities. Neurodevelopmental Manifestations,* Guildford Press, New York, pp.206-238.

Fletcher, J.M., Brookshire, B.L., Landry, S.H., Bohan, T.P., Davidson, K.C., Francis, D.J., et. al. (1996). Attention skill and executive functions in children with early hydrocephalus. *Developmental Neuropsychology, 12,* 53-76.

Fletcher, J.M., Copeland, K., Fredrick, J.A., Blaser, S.E., Kramer, L.A., Northrup, H., et.al. (2005). Spinal lesion level in spina bifida: a source of neural and cognitive heterogeneity. *Journal of Neurosurgery, 102,*268-279.

Fletcher, J.M., McCauley, S.R., Brandt, M.E., Bohan, T.P., Kramer, L.A., Francis, D.J., et.al. (1996). Regional brain tissue composition in children with hydrocephalus. Relationships with cognitive development. *Archives of Neurology, 53,* 549-557.

Fobe, J., Rizzo, A.M., Silva, I.M., Da Silva, S.P., Teixeira, C.E., De Souza, A.M., & Fernandes, A. (1999). IQ in hydrocephalus and myelomeningocele. Implications of surgical treatment. *Arq Neuropsiquiatr, 57*, 44-50.

Frank, SV, Lazarus T, Nathoo N. (2003)Visuospatial deficits in children 3-7 years old with shunted hydrocephalus. *South African Journal of Medicine,*

Friedrich, W.N., Lovejoy, M.C., Shafer, J., & Shurtleff, D.N. (1991). Cognitive ability and achievement status of children with myelomeningocele: A contemporary sample. *Journal of Pediatric Psychology, 16*, 423-428.

Golomb, J., Wisoff, J., Miller, D.C., et. al. (2000). Alzheimer's disease comorbidity in normal pressure hydrocephalus: prevalence and shunt response. *Journal of Neurology, Neurosurgery, and Psychiatry, 68*, 778-781.

Hasan, K. M., Eluvathingal, T. J., Kramer, L. A., Ewing-Cobbs, L., Dennis, M., Fletcher, J. M. (2008). White matter microstructural abnormalities in children with spina bifida myelomeningocele and hydrocephalus: a diffusion tensor tractography study of the association pathways. *J Magn Reson Imaging.* 27, 700-709.

Hirsch, J. F. (1992). Surgery of hydrocephalus: Past, present, and future. *Acta Neuropathologica, 116,* 155-160.

Holler, K.A., Fennel, E.B., Crosson, B., Boggs, S.R., & Mickle, J.P. (1995). Neuropsychological and adaptive functioning in younger vs. older children shunted for early hydrocephalus. *Child Neuropsychology, 1*, 63-73.

Hommet, C., Billard, C., Barthez, M., Lourmiere, J. M., Santini, J. J., De Toffol, B., et. al. (1999). Neuropsychologic and adaptive functioning in adolescents and young adults shunted for congenital hydrocephalus. *Journal of Child Neurology, 14,* 144-150.

Horn, D.G., Lorch, E.P., Lorch, R.F., & Culatta, B. (1985). Distractibility and vocabulary deficits in children with spina bifida and hydrocephalus. *Developmental Medicine and Child Neurology, 27,* 713-720.

Hunt, G. M., Oakeshott, P., & Kerry, S. (2005). Link between the CSF shunt and achievement in adults with spina bifida. *Journal of Neurology, Neurosurgery, and Psychiatry, 67*, 591-595.

Ito, J., Saijo, H., Araki, A., Tanaka, H., Tasaki, K., Cho, K., & Miyamoto, A. (1997). Neuroradiological assessment of visuoperceptual disturbances in children with spina bifida and hydrocephalus. *Developmental Medical Child Neurology, 39,* 385-392.

Jacobs, R. (2001). Cognitive outcome in children with myelomeningocele and perinatal hydrocephalus: A longitudinal perspective. *Journal of Developmental & Physical Disabilities, 23*, 389-405.

Kao, C.L., Yang, T.F., Wong, T.T., Cheng, L.Y., Huang, S.Y., Chen, H.S., Kao, C.L., Chan. R.C. (2001). The outcome of shunted hydrocephalic children. *Arq Neuropsiquitar, 57*, 44-50.

Koomen, I., Van Furth, A. M., Grobbee, D.E., Roord, J.J., Jennekens-Schinkel, A. (2004). Neuropsychology of academic and behavioral limitations in school-age survivors of bacterial meningitis. *Developmental Medicine & Child Neurology, 46,* 724-732.

Landry, S. H., Jordan, T., & Fletcher, J. M. (1994). Developmental outcomes for children with spina bifida. In M. G. Tramontana & S. R. Hooder (Eds.). *Advances in child neuropsychology* (Vol. 2 pp 85-118). New York: Springer-Verlag.

Lumenta, C.B. & Skotarczak, U. (1995). Long-term follow-up in 233 patients with congenital hydrocephalus. *Childs Nerv Syst., 11*, 173-175.

Mataro, M., Antonia Poca, M., Sahuquillo, J., Cuxart, A., Iborra, J., et. al. (2005). Cognitive changes after cerebrospinal fluid shunting in young adults with spina bifida and assumed arrested hydrocephalus. *Journal of Neurology, Neurosurgery, and Psychiatry, 68,* 615-621.

Mazur, J.M., Aylward, G.P., Colliver, J., Stacey, and Menelaus M. (1988). Impaired mental capabilities and hand function in myelomeningocele patients. *Z Kinderchir, 43*, 24-27.

Menkes, J. (2000) *Textbook of Child Neurology, 6th ed.* Lippnicott Willams & Wilkins, Philadelphia, PA.

Merkelbach, S., Schweizer, H., & Muller, M. (2000). Cognitive outcome after bacterial meningitis. *Acta Neurol Scand, 102,* 118-123.

Muen, W.J. & Bannister, C.M. (1997). Hand function in subjects with spina bifida. *European Journal of Pediatric Surgery, 1*, 18-22.

Patwardhan, R.V. & Nanda, A. (2005). Implanted ventricular shunts in the United States: the billion-dollar-a-year cost of hydrocephalus treatment. *Neurosurgery, 56*, 144-145.

Pentland, L.M., Anderson, V.A., & Wrennall, J.A. (2000). The implications of childhood bacterial meningitis of language development. *Child Neuropsychology, 6,* 87-100.

Ralph, K., Moylan, P., Canady, A., & Simmoms, S. (2000). The effects of multiple shunt revisions on neuropsychological functioning and memory. *Neurol Res, 22*, 131-136.

Rani, J., Elisabeth, N., & Vicki, A. (2001). Cognitive outcome in children with myelomeningocele and perinatal hydrocephalus: A longitudinal perspective. *Journal of Developmental and Physical Disabilities, 13*, 389-405.

Sahuquillo, J., Rubio, E., Cordian, A., et. al. (1991). Reappraisal of the intracranial pressure and cerebrospinal fluid dynamics in patients with the so-called "Normal Pressure Hydrocephalus" syndrome. *Acta Neurochir, 112,* 50-61.

Savolainen, S., Paljarvi, L., & Vapalhati, M. (1999). Prevalence of Alzheimer's disease in patients investigated for presumed normal pressure hydrocephalus: a clinical and neurpathological study. *Acta Neurochir, 141,* 849-853.

Scott, M.A., Fletcher, J.M., Brookshire, B.L., Davidson, K.C., Landry, S.H., Bohan, T.C., et. al.(1998). Memory functions in children with early hydrocephalus. *Neuropsychology, 12,* 578-589.

Shafer, J., Friedrich, W.N., Shurtleff, D.B., & Wolf, L. (1985). Cognitive and achievement status in children with myelomeningocele. *Journal of Pediatric Psychology, 10*, 325-336.

Silver, B. V. & Chinarian, J. (1997). Neurologic improvement following shunt placement for post-traumatic hydrocephalus in a child. *Pediatric Rehabilitation, 2, 123 – 126.*

Silverberg, G.D., Leventhal, E., Sullivan, E.V., et. al. (2002). Assessment of low-flow drainage as a treatment for AD: Results of a randomized pilot study. *Neurology, 59,* 1139-1145.

Snow, J.H. (1999). Executive processes for children with spina bifida. *Children's Health Care, 28,* 241-253.

Stambrook, M., Cardoso, E., Hawryluk, G.A., Erirkson, P., Piatek, D., & Sicz, G. (1988). Neuropsychological changes following the neurosurgical treatment of normal pressure hydrocephalus. *Archives of Clinical Neuropsychology, 4,* 323-330.

Tew, B. & Laurence, K.M. (1975). The effects of hydrocephalus on *intelligence*, visual perception and school attainment. *Developmental Medicine & Child Neurology, 17*, 129-134.

Tew, B., Laurence, K.M., & Richards, A. (1980). Inattention among children with spina bifida and hydrocephalus. *Zeitschrift fur Kinderchirugie, 31,*381-385.

Thomas, G., McGirt, M.J., Woodworth, G., Heidler, J., Rigamonti, D., Hillis, A.E., & Williams, M.A. (2005). Baseline neuropsychological profile and cognitive response to cerebrospinal fluid shunting for idiopathic normal pressure hydrocephalus. *Dementia and Geriatric Cognitive Disorders, 20,* 163-168.

Thompson, N.M., Fletcher, J.M., Chapieski, L., Landry, S.H., Miner, M.E., & Bixby, J. (1991). Cognitive and motor abilities in preschool hydrocephalics. *Journal of Clinical and Experimental Neuropsychology, 13,* 245-258.

Tubbs, R. S. & Oakes, W. J. (2004). Treatment and management of Chiari II malformation: an evidence based review of the literature. *Childs Nervs. Sys, 20,* 375-381.

Vachha, B. (2003). Language differences in children with myelomeningocele and shunted hydrocephalus. *The Sciences & Engineering, 64*, 133.

Vachha, B & Adams, R.C. (2005). Memory and selective learning in children with spina bifida-myelomeningocele and shunted hydrocephalus: A preliminary study. *Cerebrospinal Fluid Research, 2,* 10.

Verrees, M., & Selman, W. (2004). Management of normal pressure hydrocephalus. *American Family Physician, 70*, 1071–1085.

Vernet, O., Camiche, R., & De Tribolte, N. (1990). Long-term results after ventriculo-atrial shunting in children. *No To Shinke,42*, 1167-1171.

Victor, M., & Ropper, A. H. (2001). *Principles of Neurology seventh edition.* McGraw-Hill, New York.

Wills, K., Holmbeck, G., Dillion, K., & Mclone, D. (1990). Intelligence and achievement in children with myelomeningocele. *Journal of Pediatric Psychology, 15,* 161-176.

Wostyn, P. (1994). Intracranial pressure and Alzheimer's disease: a hypothesis. *Medical Hypotheses, 43,* 219-222.

Wostyn, P. (2004). Can chronic increased intracranial pressure or exposure to repetitive intermittent intracranial pressure elevations raise your risk for Alzheimer's disease? *Medical Hypotheses, 62,* 925-930.

Yates, K.O., Enrile, E., Loss, N., Blumenstein, E., & Delis, D.C. (1995). Verbal learning and memory in children with myelomeningocele. *Journal of Pediatric Psychology, 20,* 801-812.

Appendix

Tables of Results

Table 1

Demographic characteristics collectively and by group

	N	Gender	Mean Age	[1]Mean Number of Shunt Events	[2]Mean Number of Shunt Infections
Collective	44	Males = 21	11.11	2.27	1.50
		Females = 23	SD = 2.76	SD = 1.28	SD = 0.84
Group 1	12	Males = 7	10.67	3.33	1.50
		Females = 5	SD = 3.72	SD =2.16	SD = 0.84
Group 2	15	Males = 5	11.41	1.50	0
		Females = 10	SD = 2.33	SD = 0.80	0
Group 3	17	Males = 9	11.24	0	0
		Females = 8	SD = 2.88	0	0

1 = Group 3 was not included in this analysis because they had no history of shunt events. 2= Groups 2 and 3 were not included in this analysis because they had no history of shunt infections.

Table 2

Test Results for All Patients, Collapsed Across Groups (N = 44)

	Median	Mean	Std. Deviation
FSIQ (ss)	81	81.60	16.66
VCI (ss)	85	81.06	17.41
PRI (ss)	94	89.23	17.37
WMI (ss)	91	85.68	19.54
PSI (ss)	80	82.97	14.70
WCST-C (s)	2.00	2.38	1.39
Trails A (z)	-2.47	-2.34	1.78
Trails B (z)	-3.15	-2.90	2.73
CVLT-C SD (z)	-0.50	-1.03	1.52
CVLT-C LD (z)	-0.50	-.94	1.64
RCFT Copy (z)	-0.49	-.65	1.34
RCFT Delay (z)	-1.51	-1.82	1.59
Peg Board D (z)	-1.26	-2.00	2.37
Peg Board ND (z)	-1.46	-2.00	1.67

FSIQ = Full Scale Intelligence Quotient, VCI = Verbal Comprehension Index, PRI = Perceptual Reasoning Index, WMI = Working Memory Index, PSI = Processing Speed Index, WCSTC = Wisconsin Card Sorting Test, categories completed, CVLT-C SD = California Verbal Learning Test Child version short delay, CVLT-C LD = California Verbal Learning Test Child version long delay, D = dominant hand, ND = non dominant hand, ss = standard score, s = score obtained, z = z-score.

Table 3

Neuropsychological Test Results by Group

Test	N	Mean	Std. Deviation	Median	Effect Size
FSIQ (ss)					
Group 1	12	*70.67	15.16	65.50	5.32
Group 2	15	*73.67	14.98	75.50	5.97
Group 3	17	93.18	8.27	95.00	
VCI (ss)					
Group 1	12	77.33	18.30	67.00	2.87
Group 2	15	73.25	13.90	76.50	3.66
Group 3	17	91.41	13.27	95.00	
PRI (ss)					
Group 1	12	*71.00	15.06	68.00	5.11
Group 2	15	*82.67	17.83	84.00	5.42
Group 3	17	100.29	8.06	97.00	
WMI (ss)					
Group 1	12	*70.83	24.47	77.50	4.97
Group 2	15	*78.08	15.19	77.00	5.13
Group 3	17	96.94	14.21	97.00	
PSI (ss)					
Group 1	12	68.17	10.07	71.50	1.22
Group 2	15	79.25	9.86	80.00	1.71
Group 3	17	91.31	14.06	95.00	
WCST					
Categories(s)	12	1.50	1.05	1.50	3.21
Group 1	15	1.75	0.97	1.50	3.33
Group 2	17	*3.19	1.38	4.00	
Group 3					
Trails A (z)					
Group 1	12	-2.73	0.95	-2.47	2.13
Group 2	15	-2.95	1.97	-3.00	2.32
Group 3	17	-1.74	1.77	-1.23	
Trails B (z)					
Group 1	12	-4.30	2.52	-5.00	2.13
Group 2	15	-3.29	3.28	-4.00	2.32
Group 3	17	-2.10	2.20	-1.32	

CVLT-C SD (z)					
Group1	12	-3.10	1.52	-3.00	5.21
Group2	15	*-1.48	1.46	-1.25	
Group3	17	-0.12	0.63	0.00	5.73
CVLT-C LD(z)					
Group 1	12	-3.15	1.64	-4.50	5.21
Group 2	15	*-1.42	1.51	-1.25	
Group 3	17	0.00	0.78	0.00	5.73
RCFT Copy (z)					
Group 1	12	-2.71	1.90	-3.00	4.11
Group 2	15	-0.71	1.10	-0.54	
Group 3	17	-0.07	0.48	-0.30	4.31
RCFT Long Delay (z)					
Group 1	12	-3.85	1.77	-4.50	4.11
Group 2	15	*-2.15	1.61	-1.57	
Group 3	17	-0.99	0.79	-1.13	4.31
Peg Board D (z)					
Group 1	12	-2.88	0.65	-3.00	2.77
Group 2	15	-3.37	3.33	-2.63	2.82
Group 3	17	-0.73	0.89	-0.33	
Peg Board ND (z)					
Group 1	12	-3.01	0.63	-3.00	2.77
Group 2	15	-2.90	1.86	-2.62	2.82
Group 3	17	-0.99	1.15	-0.71	

Group 1 = patients with a shunt and history of shunt infection, Group 2 = patients with a shunt and no history of shunt infection, Group 3 = patient with no history of shunt placement, FSIQ = Full Scale Intelligence Quotient, VCI = Verbal Comprehension Index, PRI = Perceptual Reasoning Index, WMI = Working Memory Index, PSI = Processing Speed Index, WCSTC = Wisconsin Card Sorting Test-categories completed, SD = short delay, LD = long delay, D = dominant hand, ND = non dominant hand, ss = standard score, s = sore obtained, z = z-score, * = significant difference.

Table 4

Number of Shunts and Correlations with Memory Test Scores

		RCFT Long Delay	CVLT-C Long Delay	CVLT-C Short Delay
Number of Shunts	Pearson Correlation	-.541	-.609	-.598
	Sig. (2-tailed)	.001	.000	.000

Table 5

Number of Shunts and correlations with IQ Test Scores

	FSIQ	*VCI*	*PRI*	*WMI*	*PSI*
Number of Shunts	-.642	-.258	-.571	-.573	-.633
Sig. (2-tailed)	.003	.072	.000	.013	.001

FSIQ = Full Scale Intelligence Quotient, VCI = Verbal Comprehension Index, PRI = Perceptual Reasoning Index, WMI = Working Memory Index, PSI = Processing Speed Index

Table 6

Number of Shunt Infections and correlations with IQ Test Scores

	FSIQ	*VCI*	*PRI*	*WMI*	*PSI*
Number of Shunts	-.228	-.123	-.274	-.177	-.102
Sig. (2-tailed)	.076	.157	.071	.092	.073

FSIQ = Full Scale Intelligence Quotient, VCI = Verbal Comprehension Index, PRI = Perceptual Reasoning Index, WMI = Working Memory Index, PSI = Processing Speed Index

Table 7

ANOVA of Shunted Group vs. No Shunt Group on Visually-Based Tasks

	Sum of Squares	Mean Square	F	Sig.
BLOCKD	130.140	32.535	4.217	.009
PCON	128.962	32.241	6.593	.001
MATR	125.097	31.274	4.020	.011
CODING	102.691	25.673	4.573	.006
PCOMPL	208.116	52.029	9.531	.000

BLOCKD = Block Design, PCON = Picture Concepts, MATR = Matrix Reasoning, PCOMPL = Picture Completion

Table 8

Number of Shunts and Correlations with Visually-Based Tasks

		PRI	BLOCKD	PCON	CODING	MATR	PCOMPL	RCFT COPY
	N	44	44	44	44	44	44	44
SHUNTS	*r*	-.521	-.483	-.352	-.478	-.492	-.500	-.762
	Sig.	.001	.004	.045	.005	.004	.003	.000
	N	44	44	44	44	44	44	44

PRI = Perceptual Reasoning Index, BLOCKD = Block Design, PCON = Picture Concepts, MATR = Matrix Reasoning, PCOMPL = Picture Completion, REYCOP = RCFT Copy

Table 9

Comparison of ESL and Non-ESL test scores

	ESL (N = 19)	Non-ESL (N = 25)
FSIQ *	74 ss (SD = 9)	86 ss (SD = 7)
VCI*	67 ss (SD = 10)	90 ss (SD = 8)
PRI	88 ss (SD = 9)	91 ss (SD = 6)
WMI	81 ss (SD = 10)	89 ss (SD = 6)
PSI	82 ss (SD = 8)	84 ss (SD = 7)
WCST	-2.38 z (SD = 1.36)	-2.38 z (SD = 1.24)
Trails A	-1.98 z (SD = .36)	-2.15 z (SD = .45)
Trails B	-3.10 z (SD = .61)	-2.95 z (SD =.86)
CVLT-C SD	-1.04 z (SD = 0.5)	-1.04 z (SD = .04)
CVLT-C LD*	-0.73 z (SD = .05)	-1.07 z (SD = 0.4)
RCFT Copy*	-0.29 z (SD = .27)	-0.88 z (SD = .36)
RCFT Delay*	-2.10 z (SD = .44)	-1.64 z (SD = .69)
Pegboard D*	-1.42 z (SD = .37)	-2.35 z (SD = .77)
Pegboard ND*	-1.57 z (SD = .41)	-2.16 z (SD = .79)

* = Significant difference between groups (*p* <.05). FSIQ = Full Scale Intelligence Quotient, VCI = Verbal Comprehension Index, PRI = Perceptual Reasoning Index, WMI = Working Memory Index, PSI = Processing Speed Index, WCSTC = Wisconsin Card Sorting Test-categories completed, SD = short delay, LD = long delay, D = dominant hand, ND = non dominant hand, ss = standard score, s = sore obtained, z = z-score.