The Relationship of Corpus Callosum and Cingulate Gyrus Surface Areas with Intelligence Scores in Persons with Early Hydrocephalus

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The Relationship of Corpus Callosum and Cingulate Gyrus Surface Areas with Intelligence Scores in Persons with Early Hydrocephalus

Heather Gerschler

A thesis submitted to the faculty of Brigham Young University in partial fulfillment of the requirements for the degree of Master of Science

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ABSTRACT

The Relationship of Corpus Callosum and Cingulate Gyrus Surface Areas with Intelligence Scores in Persons with Early Hydrocephalus

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This study served as a pilot study of cingulate gyrus surface areas and their relation to intelligence in individuals with hydrocephalus. Surface areas of the corpus callosum and cingulate gyrus regions were compared between individuals with early hydrocephalus (n = 9) and controls (n = 7). Subsequently, the surface areas were correlated with full-scale intelligence scores and the verbal and nonverbal discrepancy scores.

Corpus callosum surface areas were significantly smaller in participants with hydrocephalus. These areas also robustly correlated with full-scale intelligence scores. Although the cingulate gyrus did not differ significantly between the groups, the cingulate gyrus regions were increasingly divergent the more posterior the region. Additionally, the caudal anterior and the posterior cingulate gyrus regions had only moderate positive correlations with full-scale intelligence scores. Although the participants with hydrocephalus had a significantly lower mean performance IQ compared to verbal IQ, the discrepancy scores did not correlate significantly with any of the regions of interest.

Keywords: hydrocephalus, corpus callosum, cingulate gyrus, intelligence scores
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The Relationship of Corpus Callosum and Cingulate Gyrus Surface Areas with Intelligence Scores in Persons with Early Hydrocephalus

Hydrocephalus is a condition that affects approximately 1 in 1000 babies born and is acquired due to a variety of causes each year by many more people of all ages (Robinson & Toporek, 1999). There is a wide range in neuropsychological functioning of people who have hydrocephalus (e.g., see Bigler 1988). Recent studies have examined trends in cognitive functioning as it relates to white and/or gray matter (Fletcher, Bohan, et al., 1992; Fletcher, Bohan, et al., 1996; Fletcher, McCauley, et al., 1996). The present study is a preliminary examination of the relationship between two midline structures, the corpus callosum (white matter) and the cingulate gyrus (gray matter), with intelligence scores, in nine participants with early hydrocephalus. The study will specifically examine the relationship of the midline structures with verbal and nonverbal skill differences that are often found in children with hydrocephalus.

Cerebrospinal Fluid and Hydrocephalus

Cerebrospinal fluid (CSF) is a clear fluid that is made from blood plasma. It is chiefly produced by the choroid plexus, which is a structure lining the floor of the lateral ventricle and the roof of the third and fourth ventricles. It has been suggested that extrachoroidal (cerebral) sites may also produce as much as one-third of the CSF (see discussion in Fishman, 1992, p. 32-33). The CSF provides physical support and cushioning protection for the brain, intracerebral transport of nutrients and waste, and control of the chemical environment of the central nervous system (Bigler & Clement, 1997; Fishman, 1992).
CSF is in the ventricles and in the subarachnoid spaces, which cover the entire surface of the brain and spinal cord. The ventricular system consists of two lateral ventricles, which are connected by the foramina of Monro to a midline third ventricle. The aqueduct of Sylvius (also known as the cerebral aqueduct) connects the third ventricle to the fourth. The fourth ventricle is in the brainstem and communicates with the subarachnoid spaces by way of the foramen of Magendie and the foramina of Luschka. The CSF circulates from the ventricles to the subarachnoid space. It is absorbed back into the blood vessels through projections of arachnoid membrane, called arachnoid villi, in the superior sagittal sinus and other venous structures (Fishman, 1992).

Hydrocephalus is defined as an accumulation of CSF within the cranial vault. It is most frequently caused by an obstruction of CSF flow somewhere along its path (Del Bigio, 1993). However, the failure of CSF to reabsorb or the overproduction of CSF can also cause hydrocephalus (Bigler & Clement, 1997). Hydrocephalus is further categorized into communicating and non-communicating forms. Communicating hydrocephalus occurs when CSF communicates (passes through) the ventricles to the subarachnoid space; however, there is resistance to drainage in the subarachnoid space. Non-communicating hydrocephalus (also referred to as obstructive) occurs when the flow of CSF is blocked within the ventricular system, including at the foramina of Luschka or the foramen of Magendie (Robinson & Toporek, 1999). Thus, communicating hydrocephalus is an extraventricular obstruction, and non-communicating hydrocephalus is an intraventricular obstruction (Fishman, 1992).

Although there are a variety of causes for this condition, ventricular dilation is the result (Del Bigio, 1993). With obstruction, the ventricles typically expand in a posterior-
to-anterior direction. If left untreated, this expansion causes cerebral edema. It is believed that the edema initially affects white matter, and then with progression, it affects gray matter (Fletcher, McCauley, et al. 1996).

Active or progressive, hydrocephalus is characterized by increasing ventricular dilation (Fishman, 1992). Currently, progressive hydrocephalus is treated with a shunt. A shunt is a flexible tube that is placed into the lateral ventricle and diverts the flow of the CSF to another region of the body, usually the peritoneal cavity or atrium (Mataró, Junqué, Poca, & Sahuquillo, 2001). Hydrocephalus is considered arrested or compensated when ventricular expansion stops (Fishman, 1992).

**Common Etiologies of Early Hydrocephalus**

Infection, inflammation, malformation, metabolic disease, trauma, or tumor may cause hydrocephalus (Holler, Fennell, Crosson, Boggs, & Mickle, 1995). Early hydrocephalus is the term used in this study to refer to cases of hydrocephalus that are congenital or are acquired shortly after birth. The three principles etiologies of congenital hydrocephalus are aqueductal stenosis, Dandy-Walker syndrome, and spina bifida. The fourth principle etiology of early hydrocephalus is intraventricular hemorrhage (IVH) in premature infants (Fletcher, Francis, et al., 1992).

Aqueductal stenosis is a form of hydrocephalus in which there is a blockage of CSF at the aqueduct of Sylvius. The obstruction is due to a congenital narrowing of the aqueduct (Klaas, Hannay, Caroselli, & Fletcher, 1999), which develops at 12 to 16 weeks gestation (Fletcher, Brookshire, Bohan, Brandt, & Davidson, 1995). Hannay, Fletcher, and Brandt (1999) state that aqueductal stenosis is a rare disorder with a prevalence of
about 1 per 17,000 births. However, aqueductal stenosis accounts for about 20% of the congenital cases of hydrocephalus (Brookshire, et al., 1995b).

Dandy-Walker syndrome is a brain malformation that is characterized by an enlargement of the fourth ventricle and a partial or complete absence of the cerebellar vermis (Robinson & Toporek, 1999). The fourth ventricle cyst that is characteristic of the syndrome causes hydrocephalus in 70% - 80% of the cases. Dandy-Walter syndrome is also considered quite rare, occurring in about 1 per 30,000 live births (Hannay, et al., 1999).

Spina bifida is a term used to describe a broad category of disorders that result from anomalous closure of the neural tube. In meningocele and myelomeningocele (also called meningo(myelo)cele) there is a lesion at the caudal end of the spine, often causing motor and sensory deficits (Fletcher, Francis, et al., 1992). With myelomeningocele, the spinal cord and surrounding tissues are exposed, usually in a sac, and the back must be closed surgically (Wills, 1993). Among children with myelomeningocele, about 80% - 90% have hydrocephalus due to the presence of the Arnold Chiari II malformation (Klaas, et al., 1999). This malformation is an elongation of the cerebellum (cerebellar tonsils) which protrudes down the foramen magnum, crowding the brain stem and spinal cord, and blocking the flow of CSF at the level of the fourth ventricle (Brookshire, et al., 1995a). The occurrence of spina bifida myelomeningocele is about 0.5 - 1.0 per 1,000 live births (Hannay, et al., 1999) and is the most common congenital etiology of hydrocephalus (Klaas, et al., 1999).

Hydrocephalus that occurs perinatally is often a consequence of prematurity and low birth weight. Approximately 40% of premature infants experience an IVH
(Robinson & Toporek, 1999). Severe IVH into the lateral ventricles and surrounding tissues result in the obstruction of the subarachnoid spaces, which interferes with the absorption of CSF (Brookshire, et al., 1995a).

**The Corpus Callosum: Topography and Current Views of Its Role**

The two cortical hemispheres of the brain are connected by the corpus callosum, the largest fiber system in the brain. The basic structure of the corpus callosum begins to develop at about the 7th week of gestation and continues through the 20th week. At this point it has its essential appearance; however, it continues to thicken during the rest of gestation and after birth. Other than the rostrum, the corpus callosum develops from an anterior to posterior direction. The rostrum (the most anterior segment) develops between 18 and 20 weeks. A disturbance in the process can cause a range of possible defects, including partial or complete agenesis (Hannay, et al., 1999, Smith & Rourke, 1995).

There are currently two main theories concerning the role of the corpus callosum. The first is that the callosal connections facilitate interhemispheric transfer of information. Thus, they promote processing by integrating input that is initially lateralized. The second theory is that callosal fibers are inhibitory and allow for hemispheric specialization of functioning (Fletcher, et al., 1992; Gazzaniga, Ivry, & Mangun, 1998; Hannay, et al., 1999). Thus far, the two theories generally appear to be incongruent with each other, for example, Gazzaniga, et al. (1998) titled their discussion of the subject, “Interhemispheric Communication: Cooperation or Competition?” (p.340). In a brief overview of the topic, Hannay, et al. (1999) concluded that the
research is not entirely conclusive; however, the faciliatory model of the corpus callosum tends to have more support.

It is clear from postmortem research on humans and primates that the corpus callosum is topographically organized. Klaas, et al. (1999) divided the corpus callosum into seven areas (see Figure 1) that have been found to connect specific cortical regions of each hemisphere. The first area, the rostrum, contains fibers that connect prefrontal and inferior premotor areas. The genu, the second area, connects the prefrontal region. The third area, the rostral body, has fibers that connect premotor motor areas. The anterior midbody, the fourth area, has fibers that connect motor areas. The fifth area is the posterior midbody; it connects somaesthetic and posterior parietal regions. The isthmus is the sixth area; it connects the superior temporal and posterior parietal areas. The splenium, the seventh area, connects the occipital and inferior temporal cortical regions.

Funnell, Corballis, and Gazzaniga (2000) presented a functional topography of the corpus callosum and the anterior commissure (see Figure 1). They assert that the anterior-to-posterior organization of the corpus callosum results in the following modality-specific regions. The anterior commissure transfers olfactory information, the rostrum of the corpus callosum transfers higher cognitive information, and the anterior midbody transfers motor input. Additionally, the posterior midbody transfers somatosensory information, the isthmus transfers auditory input, and the splenium transfers visual information. Due to this topographic organization, lesions to specific areas to the corpus callosum may result in predictable deficits in interhemispheric transfer of information.
Cingulate Gyrus: Topography and Functions

The cingulate cortex spans the rostral, dorsal, and splenial parts of the corpus callosum like an arc. In the human brain the primary ventral and dorsal border of the cingulate cortex is the cingulate sulcus. The main identifying features that distinguish the cingulate cortex from other cortical regions are its cytoarchitecture and thalamic connections. A main feature of the cytoarchitecture is the prominence of the neurons in layer V, which contain many neurons that project into motor systems. Additionally, there may be about 20 thalamic nuclei that project to the cingulate cortex (Vogt, 1993).

The cingulate cortex is subdivided into two major parts: the anterior and posterior. The anterior and posterior cingulate cortices differ in cellular structure and connections. Notably, the cortical layer IV is poorly developed in the anterior cingulate cortex; thus, it is called agranular cortex. The posterior cingulate cortex, however, is considered granular cortex because layer IV is well developed, as is found in the primary visual, auditory, and somatosensory cortex (Clark & Boutros, 1999; Vogt, 1993).

Clark and Boutros (1999) delineate four areas of the anterior cingulate cortex and three areas of the posterior cingulate cortex (see Figure 2). Most of the anterior cingulate cortex is formed around the genu of the corpus callosum and corresponds to Brodmann’s area 24. The prelimbic area of the anterior cingulate cortex consists of the gyrus that lies in front of Brodmann’s area 24, it corresponds mainly to Brodmann’s area 32. The paragenu area of the anterior cingulate cortex wraps around the genu of the corpus callosum and corresponds primarily with Brodmann’s area 25. The fourth area of the anterior cingulate cortex, the infralimbic area, is associated with the part of the paragenu area that is located below the genu.
The anterior cingulate cortex is continuous with the posterior cingulate cortex. The main portion of the posterior cingulate cortex consists of Brodmann’s area 23. The retrosplenial area of the posterior cingulate cortex wraps around the splenium of the corpus callosum, while the parasplenial area lies beneath the splenium.

Clark and Boutros (1999) note that the anterior cingulate cortex is in the anatomical location to function as a filter and control between the emotional limbic system and the skeletomotor and autonomic aspects of the nervous system. The position of the cingulate gyrus suggests that it provides executive (or gating) function in motivation, goal-directed behavior, and neurovegetative functions. Clark and Boutros (1999) subdivide the anterior cingulate cortex into an affect division and a cognitive division. The anterior areas (Brodmann’s 25, 33, and anterior 24) are termed the affect division. This division “regulates autonomic and endocrine functions, assesses motivation and emotional content of internal and external stimuli, and plays a role in maternal-infant interactions” (p. 162). Whereas, the cognitive division (Brodmann’s 32 and posterior of area 24) controls the nociceptive (pain sensation) and skeletomotor areas, in addition to response selection in problem solving.

Vogt, Finch, and Olson (1992) called the anterior portion of the cingulate cortex the executive region and the posterior cingulate cortex the evaluative region. The anterior region is associated with the following functions: emotion, pain, maternal behavior, visceromotor and skeletomotor control, and attention to action. The posterior region is associated with the following functions: eye movements, vision, somatic function, spatial orientation, and memory (Vogt, et al., 1992).
Brain Anomalies and Volume Reductions Related to Hydrocephalus

The increased cranial pressure caused by progressive hydrocephalus can stretch and destroy the corpus callosum. This may lead to hypoplasia, in which all the structures of the corpus callosum are present but thinned. Due to the posterior-to-anterior progress of hydrocephalus, the midline white matter tracts that connect the hemispheres to the diencephalon and more caudal regions are likely to be affected. However, the more lateral white mater tracts that connect the cortical regions of each hemisphere are generally spared (Fletcher, Bohan, et al., 1992). Hydrocephalus may disrupt myelination. It may also cause a reduction of cortical thickness, especially in posterior regions, and may decrease overall brain mass (Brookshire, et al., 1995b).

In addition to the damaging mechanical effects of increased intracranial pressure, children with hydrocephalus often experience congenital brain malformations, such as partial or complete agenesis of the corpus callosum. The congenital anomalies are a result of an early disruption in neuroembryogenesis, during roughly the fourth and sixteen weeks. When multiple abnormalities occur, it indicates that the disruption was prolonged rather than being brief (Fletcher, Francis, et al., 1992).

Each of the main causes of early hydrocephalus has a typical pattern of brain insult or malformation. This is due to the difference in the timing of the various etiologies of hydrocephalus. However, there is still a good amount of variation in brain anomalies amongst patients with the same etiology (see Hannay, 2000).

Children with aqueductal stenosis may have abnormalities of the corpus callosum, including partial agenesis and hypoplasia, and less frequently manifest other malformations of the central nervous system (Brookshire, et al. 1995b; Fletcher, et al.,
1995; Hannay et al., 1999). There may also be a breaking of the tectum due to the fusion of the inferior and superior colliculi (Hannay, 2000).

Children with Dandy-Walker syndrome often experience increased head circumference, bulging occiput (the back of the head), and cranial nerve dysfunction. In addition to the cerebellar malformation of partial or complete agenesis of the cerebellar vermis, other central nervous system structural abnormalities may be present, including malformations of the heart and an absence of the corpus callosum (Robinson & Toporek, 1999).

In addition to spinal malformations, children with spina bifida may have partial agenesis and/or hypoplasia of the corpus callosum. These children may also have kinking and/or caudal herniation of the medulla. Additionally, there may be herniation of the cerebellum (Arnold Chiari II malformation) and displacement and distortion of the fourth ventricle (Brookshire, et al., 1995).

Children who experience IVH due to low birth weight may develop porencephalic cysts due to bleeding in the germinal matrix and parenchyma. Premature children may also experience other general brain insults such as hypoxia and periventricular hemorrhagic infarctions (periventricular leukomalacia). However, unlike children with congenital causes of hydrocephalus, these insults occur in brains that were initially generally normal (Fletcher, Francis, et al., 1992).

The combination of anomalous brain formation and the mechanical effects of hydrocephalus can cause brain volume reductions. Dennis, et al. (1981) stated that the biomechanical effects of hydrocephalus affect certain regions of the developing brain more severely than other regions. Cortical thinning or stretching is often asymmetric in
the anteroposterior direction, with selective rather than global thinning. As an example, the authors note that the vertex and occipital lobe are thinner or more distended than the frontal lobe.

Fletcher, Bohan, et al. (1992) found that children with early hydrocephalus related to myelomeningocele and aqueductal stenosis had a measurable reduction in the size of the corpus callosum compared to normal subjects. All patient groups (meningocele, myelomeningocele, and aqueductal stenosis) had smaller internal capsules and larger lateral ventricles, yet the centrum semiovale were of normal size. Similarly, Fletcher, Bohan, et al. (1996) found reductions in the size of the corpus callosa in the shunted hydrocephalus group, but not the unshunted, who are arrested, hydrocephalus participants. However, the lateral ventricles were larger and internal capsules were smaller in both hemispheres for children with hydrocephalus (shunted and unshunted).

Fletcher, McCauley, et al. (1996) found that children with hydrocephalus had reduced overall gray matter percentages and increased CSF percentages compared to typical children. The decrease of gray matter and increase of fluid were most prominent in the posterior regions of both hemispheres. Additionally, the researchers found that white matter percentages were significantly reduced only in the left posterior quadrant of the participants with hydrocephalus.

It is worth pointing out that there could be a reorganization of functioning of the brain, including the corpus callosum (if present), in patient populations. Studies of people with hydrocephalus, who frequently have partial agenesis, often have damage to midline white matter structures (Fletcher, et al., 1995; Fletcher, McCauley, et al., 1996).
As a result, “the topography of the normal callosum may or may not be applicable in cases of partial agenesis of the corpus callosum (Klaas et al., 1999, p. 838).”

Hannay, et al. (1999), argue that there may be a compromised opportunity for children born with malformation or damage to the corpus callosum to benefit from a maximum amount of brain plasticity. They state that the main mechanism of restoration used by the brain is to have one hemisphere subsume a particular function that is usually performed by regions in the opposite hemisphere of the brain. An early compromise of the corpus callosum could disallow for this substitution of function. As a result, damage to the corpus callosum may be a critical factor in the degree of plasticity and recovery of function in children with congenital brain malformations.

**Hydrocephalus and Neuropsychological Outcomes**

**Intelligence Scores**

In a literature review, Wills (1993) concluded that the etiology of hydrocephalus is related to differences in mean intelligence scores. For example, children with spina bifida hydrocephalus had lower intelligence scores than children with uncomplicated congenital hydrocephalus. In general, the greater number of complications related to the cause of hydrocephalus the lower the mean intelligence scores. Therefore, it is not surprising that postnatal acquisition of hydrocephalus has been associated with higher intelligence scores than prenatal causes. Once again, this is true because most cases of postnatal hydrocephalus impact an initially normal brain, whereas prenatal hydrocephalus insults a brain that has already been subject to congenital malformations.

The size of the ventricles before shunting does not correlate well with postoperative intelligence scores (Wills 1993). This may be due to the reasoning that the
complications that accompany the cause of hydrocephalus are more influential on intellectual functioning than the cause of hydrocephalus alone. However, the size of ventricles after shunting is consistently associated with intelligence. Ventricular expansion above a certain threshold lowers intelligence. As with very large ventricles, slit ventricles (which may be caused by a shunt that drains too much) also tend to correlate with lower intelligence scores. In line with this, scores also drop during times of shunt malfunction (often resulting in increased intracranial pressure) and tend to increase again after shunt revision (Wills 1993). These findings suggest that the wellbeing of the person at the time of testing correlates better with an intelligence score than the amount of initial ventricular expansion.

**Verbal Ability**

Although it is commonly stated that verbal skills fare much better than nonverbal skills in children with hydrocephalus, there are still characteristic deficits in verbal abilities. Brookshire, et al. (1995a) studied specific language difficulties in three etiology groups (aqueductal stenosis, spina bifida, and prematurity) using a matched control design. The children were tested on phonological awareness, semantics, fluency, and word retrieval. The researchers found that all hydrocephalus groups performed below controls on all measures. The children who were shunted secondary to spina bifida tended to perform more poorly than the other five groups. Except for poor performance on the word generation task, children with hydrocephalus due to aqueductal stenosis performed more similarly to the controls than other hydrocephalus groups.

There is a tendency among children with hydrocephalus for hyperveral behavior, also called the cocktail party syndrome (Brookshire, et al., 1995a; Wills, 1993).
According to Wills (1993) these children (a) are verbose; (b) frequently express irrelevant, inappropriate, and nonconstructive utterances; (c) demonstrate poor descriptive speech, analogical reasoning, and language comprehension; and (d) present social disinhibition. Brookshire and colleagues (1995a) noted that this syndrome occurs more often in females who are more severely physically disabled. These behaviors do tend to decline with age, and their presence at age 10 correlate significantly with subnormal intelligence. Hyperveral behavior is frequently proposed to be due to an attentional deficit rather than a language deficit.

Wills (1993) concluded from her literature review that children with hydrocephalus due to spina bifida typically follow normal verbal developmental milestones. Conversational speech is usually normal in intonation, rate, fluency, and articulation. A few children with spina bifida have articulation deficits and some show hypersensitivity to sound and intolerance to noise. As stated previously, some children with hydrocephalus due to spina bifida demonstrated hyperveral behavior. Spina bifida hydrocephalus is specifically related to difficulties with word finding, sentence memory, and grammatic comprehension.

Culatta and Young (1992) found that children with hydrocephalus due to spina bifida have attentional/perceptual problems that lead to specific language deficits. They especially struggle with attending to or isolating relevant from irrelevant stimuli. As a result, they have problems with discourse and abstract vocabulary. These children have fluent verbal expression, yet their utterances are often not related to topic or context.
Attention, Memory, Executive Function, and Adaptive Functions

Fletcher, Brookshire, et al. (1996) used psychometric measures of executive functions, focused attention, and selective attention to study children with three etiologies of hydrocephalus (aqueductal stenosis, spina bifida, and prematurity). They found that children with shunted hydrocephalus showed problem solving deficiencies on measures of executive functions (Tower of London, Wisconsin Card Sorting Test). They also performed more poorly on measures of selective attention (Stroop color and word test) and focused attention (cancellation tests). However, the differences did not suggest problems with executive function and attention related to frontal lobe control. Instead, children with hydrocephalus tended to have difficulties in sustaining attention and seemed to be more distractible than non-hydrocephalic children. The researchers suggest that these deficiencies implicate impairment of subcortical brain structures in the posterior right hemisphere that represent part of the arousal-activation brain system.

Yeates, Enrile, Loss, Blumenstein, and Delis (1995) studied specific deficits in verbal learning and memory of children with hydrocephalus related to spina bifida. They found that the children with spina bifida recalled as many words as controls on the first learning trial, but learned words more slowly across trials, so their overall recall was lower. As well, there was a pronounced recency effect on learning trials. Yeates and colleagues argued that the results suggest that children with hydrocephalus due to spina bifida encoded and stored the words adequately, but they had difficulty retrieving them spontaneously. They suggest that white matter abnormalities may underlie these retrieval problems.
When children shunted for hydrocephalus secondary to spina bifida were compared at younger versus older ages, specific differences were found (Holler, Fennell, Crosson, Boggs, & Mickle, 1995). The entire sample showed the typical impairments in motor, performance, verbal, communication, and learning skills. However, older children were impaired compared to younger children on a measure of long-term verbal memory. Secondly, older children demonstrated more difficulty with specific adaptive functions – socialization, learning, and conduct. There are many possible explanations for this. For example, it could be due to increasing social learning demands as age increases, rather than an actual deterioration of appropriate behavior with age.

Wills (1993) noted several areas of impoverished performance in children with spina bifida hydrocephalus. First, these children may be able to focus and sustain concentration in a rote manner during a simple reaction test but may still have difficulty with tasks that demand more active scanning, sequencing, planning, mental tracking, shifting attention, or inhibiting over-learned responses. Secondly, these same children may exhibit the nonverbal learning disability syndrome, which “involves visuospatial, motor, and tactile deficits, impaired conceptual and problem-solving abilities, especially in dealing with novel situations, fluent rote language, and inept interpersonal relating (pp. 256 - 257).” It has been hypothesized that this involves the dysfunction of white matter association tracts. However, other types of cerebellar dysplasia similar to Arnold-Chiari II malformations (such as in Fragile X syndrome and autism) have similar disinhibited, socially inept behavior patterns.

There are points worth noting about memory research and behavioral findings from the literature review by Mataró, et al. (2001). First, there has not been systematic
and comprehensive memory testing with children with hydrocephalus. The research that has been done has had mixed results. Therefore, there has not yet been an established pattern of memory deficits that relate to various factors associated with hydrocephalus. Secondly, research on behavior problems with children with hydrocephalus has been limited. The research that has been done indicates that more severe intellectual disability is a key factor in problematic behavior. Children with hydrocephalus but without much intellectual disability did not differ from controls; whereas children with both hydrocephalus and intellectual disability have significantly more behavioral problems.

**Verbal and Nonverbal Skill Discrepancies**

Dennis, et al. (1981) studied 78 children with early hydrocephalus (each of the primary etiologies and additional causes such as infection or unknown etiology). They found that children with hydrocephalus tend to have nonverbal intelligence that is developed less well than verbal intelligence, with aqueductal stenosis being related to the largest verbal and nonverbal discrepancies. The researchers argued that the discrepancy was due to developmental brain anomalies and other symptoms that children with hydrocephalus are prone to, rather than the hydrocephalic condition or its treatment. For example, the group of children with motor deficits also had lower performance intelligence scores, which brought down their full-scale scores. Likewise, visual disturbances and seizures, which occur more frequently in children with hydrocephalus, are related to lower performance intelligence scores.

Fletcher, Francis, et al. (1992) stated that children who develop hydrocephalus early in development are not usually mentally deficient (e.g., score below 70 on a Wechsler Intelligence Scale), but typically demonstrated a decrease in their overall level
of cognitive development. They too noted a discrepancy in the development of language
versus nonverbal cognitive skills (e.g., perceptual matching, visual-motor processing).
Like Dennis, et al. (1981), in their study of this discrepancy, they found that the
aqueductal stenosis group had a larger gap between the verbal and nonverbal scores than
the spina bifida or premature hydrocephalus groups. The gap between verbal and
nonverbal measures was less in the spina bifida and premature groups because the verbal
skills were lower than those of the aqueductal stenosis group. The authors suggested this
might reflect the higher frequency of other brain anomalies in these groups.

In their five-year longitudinal study, Brookshire, et al. (1995b) used measures
from the McCarthy Scales of Children’s Abilities, the WISC-R, and a composite of
neuropsychological tests to study children with shunted hydrocephalus, children with
arrested hydrocephalus, and control participants. They found that children with shunted
hydrocephalus generally do have poorer nonverbal skills in comparison to verbal skills.
They also had higher rates of significant verbal and nonverbal discrepancies in their
Wechsler Intelligence Scale for Children—Revised (WISC-R) Verbal IQ (VIQ) and
Performance IQ (PIQ) scores.

Brain Volume Correlates with Neuropsychological Outcomes

Fletcher, Bohan, et al. (1992) studied brain correlates of the discrepancy of poorer
nonverbal versus verbal skills in three etiology groups (meningomyelocele, meningocele,
and aqueductal stenosis), compared to matched groups without shunted hydrocephalus.
They found that nonverbal skills correlate with the right (but on left) lateral ventricle and
with the area of the right and left internal capsules. The verbal skills correlate with the
left (not the right) lateral ventricle and with the area of the left (but not right) internal
capsule. Fletcher and his colleagues also found that only the shunted spina bifida and aqueductal stenosis groups had both smaller corpus callosum measurements and discrepancies in verbal and nonverbal functioning. These findings highlight the importance of the corpus callosum for developing nonverbal skills.

Fletcher, McCauley, et al. (1996) used MRI slices from children with three etiologies of hydrocephalus (spina bifida, aqueductal stenosis, and prematurity) to compare regional brain tissue with cognitive development. They found a correspondence of posterior (but not anterior) CSF and gray matter percentages with measures of verbal, visuospatial, and visuomotor skills. As well, they found children with hydrocephalus had reduced overall gray matter percentages that corresponded with increased CSF percentages. As expected, the increased fluid was more pronounced in the posterior than the anterior regions due to the posterior-to-anterior progression of hydrocephalus. Surprisingly, the children did not have the hypothesized lower percentages of white matter than gray matter when compared to the non-hydrocephalus group. Fletcher and his colleagues proposed that the decrease in gray matter percentages reflect several factors involved in early hydrocephalus, including (a) changes in the corpus callosum, (b) destruction of cell bodies, and (c) defects in neural migration commonly associated with congenital causes of hydrocephalus.

Corpus Callosum and Cingulate Gyrus in Relation to Intelligence Scores

There is no way to know if there is a causal relationship between a brain structure’s volume and the correlation with neuropsychological testing. However, a correlation may suggest that a certain area in the brain contributes to specific cognitive functioning. For example, Fletcher, Bohan, et al. (1992) found that nonverbal skills
correlate with the right lateral ventricle and verbal skills with the left later ventricle. Thus, the more pathological the ventricle, the lower the corresponding verbal or performance IQ. These findings support specialization of speech in the left hemisphere and visuospatial skills in the right hemisphere, even in hydrocephalus populations.

Specific to this study, smaller corpus callosum may slow interhemispheric transfer, which could lower scores for sub-test that are timed. This may relate to Wechsler scales of intelligence in which most nonverbal sub-tests are timed, yet only one verbal test (Arithmetic) is timed. Therefore, a smaller corpus callosum may be a factor in the verbal and nonverbal skill discrepancy found in people who have hydrocephalus when using this scale.

The anterior region of the cingulate cortex, which is associated with skeletomotor control, could contribute to a person’s ability to perform certain tests in an intelligence battery, such as Block Design or Object Assembly (puzzles), both which were part of the nonverbal score in the Wechsler scales. However, this does not exclude the input of the cerebellum, which is associated with fine motor control, which is often malformed in people with spina bifida and Dandy-Walker syndrome.

The posterior region of the cingulate cortex is associated with eye movements, vision, and spatial orientation, all of which are needed to perform: Coding, Block Design, Object Assembly, Symbol Search, and Mazes (which make up the bulk of the nonverbal skill measure of the Wechsler scales). The posterior cingulate is also associated with memory. All the subtests in the Wechsler scales require some form of memory: long term, short term, and/or working memory. Therefore, the integrity of the cingulate cortex, especially the posterior section, may influence intelligence scores.
Summary

The corpus callosum and cingulate gyrus are the focus of this study because hydrocephalus has been shown to adversely affect midline structures, due to the proximity to the lateral ventricles, as well as posterior cortical regions. Past studies have shown the children with hydrocephalus have reduced corpus callosum volumes and corresponding verbal and nonverbal discrepancies. The purpose of this study is to replicate corpus callosum findings while exploring cingulate gyrus surface area comparisons and possible correlation to intelligence scores and the verbal and nonverbal discrepancies that are characteristic of people with hydrocephalus.

Hypotheses

Hypothesis I. Surface area comparisons between hydrocephalus and control participants

A.) Corpus callosum surface areas will be significantly smaller for the participants with hydrocephalus compared to the matched controls.

B.) Cingulate gyrus surface areas, especially the posterior sections, will be significantly smaller for the participants with hydrocephalus compared to matched controls.

Hypothesis II. Surface area relationship with full-scale IQ scores

A.) Corpus Callosum areas will correlate with overall intelligence scores; with smaller areas associated with lower scores.

B.) Cingulate gyrus areas will correlate with overall intelligence scores; with smaller areas associated with lower scores.
Hypothesis III. Surface area relationship with verbal and nonverbal discrepancies.

A.) The corpus callosum surface areas will correlate with the verbal and nonverbal discrepancy scores; with smaller areas associated with larger discrepancies.

B.) The cingulate gyrus surface areas will correlate with the verbal and nonverbal discrepancy scores; with smaller areas associated with larger discrepancies.

Method

Subjects

Information regarding patient participants was taken from a hydrocephalus database that is being compiled at Brigham Young University. This database consists of clinical magnetic resonance imaging (MRI) studies that had been ordered during the neurosurgical care and follow-up of individuals who have been diagnosed as having hydrocephalus. There were nine participants with hydrocephalus (n=9). The specific etiologies for the participants were not available.

Information regarding control participants (n=7), who had no history of neurological disease, was taken from an existing database at Brigham Young University. Where possible, control participants were matched by age and gender. Race and socioeconomic information were not available for any of the participants. See Table 1 for summary information about gender and age.

There was no significant difference in the mean age of the participant groups. When all the subjects were included, there was no significant difference in gender
Table 1  Participant Gender and Age Information

<table>
<thead>
<tr>
<th></th>
<th>Hydrocephalus</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
</tr>
<tr>
<td>Female:</td>
<td>3</td>
<td>33.3</td>
</tr>
<tr>
<td>Male:</td>
<td>6</td>
<td>66.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>11.44</td>
<td>8.14</td>
<td>13.43</td>
<td>7.18</td>
</tr>
</tbody>
</table>

*p < .05.  **p < .01.

between the participant groups. When the two female control participants were excluded in correlation calculations, due to lack of intelligence test information, the gender became significantly different between the groups, yet age was not significantly different.

Intelligence Test Scores

Participants who were 17 years of age or older were administered the Wechsler Adult Intelligence Scale - Revised or III (Wechsler, 1981, 1997). Participants that were younger than 17 years of age were administered either the Wechsler Intelligence Scale of Children - R or III (Wechsler, 1974, 1992) or the Kaufman Assessment Battery for Children (K-ABC) (Kaufman & Kaufman, 1983). The K-ABC is used to assess children ages 2 years and 6 months through 12 years and 5 months. The Wechsler Intelligence
Scale for Children is used to assess children ages 6 through 16 years. Meanwhile, the
Wechsler Adult Intelligence Scale is used to assess people ages 16 through 74. All the
tests are standardized with a mean of 100 and a standard deviation of 15. For the
purposes of this study these intelligence test scores are considered equivalent. The mean
IQ scores for the participants are displayed in Table 2.

Often researchers have removed subjects from a study when both verbal and
performance scales are below 70 (Brookshire, et al., 1995b; Dennis, et al., 1981; Fletcher,
et al., 1995; Fletcher, Francis, et al., 1992). Fletcher, Bohan, et al. (1992) explained that
this removal is necessary when performing a discrepancy analysis, because the
relationship between the verbal IQ and the performance IQ change in relation to the
overall level of intelligence, due to test standardization. Dennis, et al. (1981) delineated
the relationship between verbal and performance IQ with normal (non-patient)
population. They stated that verbal IQ and performance IQ are most similar when near
the mean. As the full-scale IQ increases, verbal IQ is higher than performance; whereas
when overall IQ decreases, performance IQ is higher than verbal IQ. However, the one
hydrocephalus participant who scored less than 70 for verbal and performance IQ scores
was not dropped from this study. The reasoning for retaining the subject is that a
correlation, rather than a discrepancy analysis, is being performed in this study.

A verbal and nonverbal discrepancy score was determined by subtracting the
standardized nonverbal score (PIQ) from the standardized verbal score (VIQ). The mean
score is available in Table 2. A positive number indicates that the verbal score was
higher, whereas a negative number indicates that the nonverbal score was higher. A
number close to zero represent very little discrepancy. The larger the number is, positive or negative, the larger the discrepancy.

Table 2  Means and Standard Deviations on Intelligence Test Scores

<table>
<thead>
<tr>
<th></th>
<th>Hydrocephalus</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Verbal IQ</td>
<td>96.00</td>
<td>23.71</td>
</tr>
<tr>
<td>Performance IQ</td>
<td>76.89**</td>
<td>17.99</td>
</tr>
<tr>
<td>Full-scale IQ</td>
<td>85.78*</td>
<td>20.55</td>
</tr>
<tr>
<td>VIQ – PIQ</td>
<td>19.11*</td>
<td>14.35</td>
</tr>
</tbody>
</table>

Note. The scores were not available for the two female control participants.

The table abbreviations are as follows: Verbal IQ (VIQ), and Performance IQ (PIQ).

*p < .05.  **p < .01.

Dennis, et al. (1981) used a different formula for determining verbal and nonverbal discrepancy because they reasoned that it was more interpretable. However, the present study used the arithmetic difference to maintain the intelligibility of the discrepancy amounts.
**MRI Procedures**

The cingulate gyrus and corpus callosum areas were derived from MRI scans of the participants’ brains. The images were transferred from archival compact disk to a Macintosh computer for image analysis.

Three scan slices were acquired for each participant: the midsagittal slice and two parasagittal slices, five to seven millimeters to the left and right of midline. The midsagittal slice was used to measure the corpus callosum. The parasagittal slices were used to measure the cingulate gyrus.

Area estimation was accomplished by tracing the corpus callosum and cingulate gyrus with a computer mouse, using the *NIH Image* program (Rasband, 1994). The lateral ventricle was used as the anatomical marker for the inferior boundary of the corpus callosum. The callosal sulcus distinguished the boundary between the cingulate gyrus and the corpus callosum. The cingulate sulcus demarcated the superior boundary of the cingulate gyrus.

The corpus callosum was measured by tracing the whole area of the corpus callosum. Whereas, the area analysis of the cingulate gyrus was determined by subdividing it into three subsections (see Figure 3). The cingulate gyrus estimation technique was based on the subdivisions used in Killiany, et al. (2000). Vertical lines were placed at the anterior and posterior extremes of the corpus callosum. A third vertical line (serving as the midline division between caudal anterior and posterior cingulate gyrus regions) was placed in the center of the two vertical lines by averaging the distance between the outer lines. The subdivisions of the cingulate gyrus are as follows: the rostral portion of the anterior cingulate gyrus, the caudal portion of the...
anterior cingulate gyrus, and the posterior cingulate gyrus. Note that the distinction between anterior and posterior is arbitrary, rather than at the occurrence of cellular distinction between posterior and anterior cingulate cortex.

Due to the anatomical variation in the hydrocephalus scans, such as partial agenesis of the corpus callosum and mechanical displacement of midline structures, certain adjustments and approximations had to be made. The midsagittal slice was determined by examining cortical appearance, relative size of fourth ventricle, and presence of aqueduct of Sylvius. Additionally, because the posterior corpus callosum was not present in all the slices of the hydrocephalus series, the mamillary bodies were used to determine where the midline was drawn in demarcating between the caudal anterior and the posterior cingulate gyrus regions. Lastly, when the posterior corpus callosum was not present in a sagittal slice, the x-coordinate of the posterior extreme of the corpus callosum of the midsagittal slice was used to place the posterior line of the cingulate gyrus.

Two cross-sectional surface area measurements were made for the corpus callosum and the left and right regions of the cingulate gyrus. The final estimate for each participant’s corpus callosum area was the average of the two measurements. The final estimate for the cingulate gyrus regions were the sum of the averaged left and the averaged right measurements.
Statistical analysis

Hypothesis I, A and B. Four independent t-tests were used to analyze the surface areas for the corpus callosum and the three regions of the cingulate gyrus. All the control subjects (n=7) were used for these analyses. The fact that the variances were heterogeneous was taken into account. Each was a one-tailed test with the alpha level at 0.05.

Hypothesis II, A and B. Four bi-variate Pearson’s r correlation analyses were performed to determine the degree of relationship between each of the regions of interest and the full-scale intelligence test scores. The tests were one-tailed with an alpha level of 0.05. The two female control participants did not have intelligence test scores available, therefore their surface areas were excluded from this calculation (control subjects, n = 5).

Hypothesis III, A and B. Four bi-variate Pearson’s r correlation analyses were performed to assess the relationship between the regions of interest with the verbal and nonverbal discrepancy scores. The tests were one-tailed with an alpha level of 0.05. Again, the two female control participants were not included in the calculation (control subjects, n = 5).

Results

The corpus callosum showed significant differences in surface area, which significantly correlated with full-scale IQ, but only moderately correlated with the discrepancy score. On the other hand, the cingulate gyrus regions did not differ significantly in size, nor did they correlate with full-scale IQ or discrepancy scores. Lastly, there were significantly different IQ comparisons, except for verbal IQ group means.
Corpus Callosum Findings

The corpus callosum was significantly smaller for the hydrocephalus participants compared to the control participants, \( t \,(13) = 7.00, \, p < 0.001 \). (See Table 3 for the means.) Additionally, the corpus callosum had a significant positive correlation with the full-scale IQ score, \( r = 0.60, \, p = 0.01 \) (shown in Table 4). However, the surface area of the corpus callosum had only a very moderate negative relationship with the verbal and nonverbal discrepancy, \( r = -0.23, \, p = 0.22 \) (shown in Table 4).

<table>
<thead>
<tr>
<th>Hydrocephalus</th>
<th>Control</th>
<th>Comparison Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>CC</td>
<td>311.56</td>
<td>67.19</td>
</tr>
<tr>
<td>RAC</td>
<td>427.66</td>
<td>231.25</td>
</tr>
<tr>
<td>CAC</td>
<td>636.59</td>
<td>202.50</td>
</tr>
<tr>
<td>PC</td>
<td>903.35</td>
<td>456.61</td>
</tr>
</tbody>
</table>

Note. These t-tests were performed using a formula for heterogeneous variances.

The table abbreviations are as follows: Corpus Callosum (CC), Rostral Anterior Cingulate (RAC), Caudal Anterior Cingulate (CAC), and Posterior Cingulate (PC).

Measurement units: millimeters squared. *\( p < .05 \). **\( p < .01 \).
Cingulate Gyrus Findings

The cingulate gyrus region means were not significantly smaller for the hydrocephalus participants. Yet, the more posterior the region, the higher the t-value. Thus, the posterior cingulate gyrus approached significance, \( t(13) = 1.94, p = 0.08 \).

The rostral anterior cingulate gyrus had essentially no correlation to the full-scale IQ. However, the caudal anterior cingulate gyrus approached significance \( (r = 0.53, p = 0.08) \), while the posterior cingulate gyrus showed a more moderate positive relationship with full-scale IQ \( (r = 0.41, p = 0.11) \). Lastly, the three regions of the cingulate gyrus did not correlate with the discrepancy scores. (See Table 4).

<table>
<thead>
<tr>
<th></th>
<th>Full-scale IQ</th>
<th>(VIQ – PIQ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>( r = 0.60^* )</td>
<td>( r = -0.23 )</td>
</tr>
<tr>
<td>RAC</td>
<td>( r = 0.04 )</td>
<td>( r = 0.16 )</td>
</tr>
<tr>
<td>CAC</td>
<td>( r = 0.40 )</td>
<td>( r = -0.15 )</td>
</tr>
<tr>
<td>PC</td>
<td>( r = 0.35 )</td>
<td>( r = 0.11 )</td>
</tr>
</tbody>
</table>

Note. Test scores were not available for the two female participants. As a result, their surface areas were also not included in the correlation.

The table abbreviations are as follows: Corpus Callosum (CC), Rostral Anterior Cingulate (RAC), Caudal Anterior Cingulate (CAC), and Posterior Cingulate (PC).

\(^{*}p < .05\).  \(^{**}p < .01\).
**Other Findings: Intelligence Test Scores**

There were several group differences in intelligence test scores (see Table 2). The participant groups had significant differences in performance IQ, full-scale IQ, and verbal and nonverbal discrepancy scores. In addition to significant differences between the groups, participants with hydrocephalus had nonverbal scores that were significantly lower than their verbal scores (see Figure 4).

**Discussion**

The study results are consistent with previous findings in that individuals with early hydrocephalus tend to have depressed intelligence scores with nonverbal skills more affected than verbal skills (Brookshire, et al., 1995b; Dennis, et al., 1981; Fletcher, et al., 1995; Fletcher, Francis, et al., 1992). Furthermore, hydrocephalus participants had lower full-scale IQ scores (Wills, 1993) which correlated with smaller corpus callosum measurements (Fletcher, Bohan, et al., 1992; Fletcher, Bohan, et al., 1996). However, there was only a very moderate correlation between corpus callosum measurements and verbal and nonverbal discrepancies.

Although the cingulate gyrus did not differ significantly between the groups, the cingulate gyrus regions were increasingly divergent the more posterior the region. Two of the cingulate gyrus regions had moderate correlations to full-scale IQ. Additionally, the cingulate gyrus had nearly no correlation with the verbal and nonverbal discrepancy.

The corpus callosum surface areas were significantly smaller in the hydrocephalus participants. Often congenital causes of hydrocephalus disrupt the formation of the corpus callosum resulting in partial agenesis (Hannay, 2000, Smith & Rourke, 1995). Additionally, the disruptive effects of hydrocephalus on the myelination process are
believed to be a cause of reduced corpus callosum size (Brookshire, et al., 1995b).

According to Del Bigio (1993) the primary cause of myelin damage may be edema in periventricular white matter, with the secondary cause being loss due to the dilation of lateral ventricles. Thus, lack of development and subsequent damage are related to smaller corpus callosum measurements.

The corpus callosum measurements had a robust correlation with the full-scale IQ scores, as hypothesized. Thus, the smaller corpus callosum surface areas are related to lower full-scale intelligence score. Brookshire, et al. (1995b) proposed that the smaller corpus callosum measurements in individuals with early hydrocephalus appear to impact intelligence due to inefficient interhemispheric communication. Additionally, they suggest that there is a reduction in the input and output of sensory information due to damaged corpus callosum and other projection fibers, thus influencing the nonverbal cognitive functioning. These explanations appear to be supported by this study.

The full-scale IQ is made up of the combination of the verbal IQ and the performance IQ, thus each has an influence on the overall score. Fletcher, Bohan, et al. (1992) found the corpus callosum was significantly correlated with performance IQ, yet correlations with verbal IQ failed to reach significance. However, Fletcher, Bohan, et al. (1996) found both verbal and performance IQ measures correlated significantly with the corpus callosum – performance IQ having a more robust correlation. With this in mind, it could be that the very depressed performance IQ scores that were found in this study could be the main influence for the lower full-scale IQ, despite the verbal and nonverbal discrepancy scores having a very moderate correlation with the corpus callosum.
The moderate negative relationship between corpus callosum and the verbal and nonverbal discrepancy scores indicate that to a moderate degree, smaller corpus callosum measurements are associated with larger discrepancies. Dennis, et al. (1981) used a discrepancy score that was similar to the one in the present study. They found non-significant correlations with both global and regional (frontal, vertex-occipital lobe) thinning. However, they did find a significant correlation with the anteroposterior asymmetry. Other authors who have correlated white matter structures with cognitive functioning have compared a verbal measure to a nonverbal measure, rather than creating a discrepancy score between the two (Fletcher, Bohan, et al., 1992; Fletcher, Bohan, et al., 1996). The latter method appears to be a more sensitive measure of verbal and nonverbal discrepancies in relation to regional brain measurement.

The cingulate gyrus regions were not significantly smaller for the hydrocephalus participants. However, the regions were increasingly divergent the more posterior the region. This reflects the knowledge that the posterior-to-anterior progress of hydrocephalus causes more damage in posterior regions than anterior areas. Given the limitations of the present study, which will be discussed later, it is notable that the posterior cingulate gyrus approached significance. Future hydrocephalus studies that have fewer limitations are likely to find significant differences in the posterior cingulate gyrus.

The caudal anterior cingulate and the posterior cingulate areas each had a moderate positive correlation with full-scale IQ that did not reach significance. This indicates that to a limited degree, these smaller cingulate gyrus surface areas tend to correspond with lower full-scale intelligence scores. However, the rostral anterior
cingulate gyrus essentially showed no relationship with the full-scale intelligence score. The finding of posterior cingulate gyrus surface area approaching significance, in conjunction with the rostral anterior cingulate gyrus showing no correlation to full-scale intelligence scores, supports the findings of comparatively spared anterior brain regions (Dennis, et al., 1981).

The lack of relationship between the cingulate gyrus regions and the discrepancy score suggests that investigating the relationship of each region with verbal skills and performance skills individually may be a more sensitive measure. However, these results could also indicate that the transfer of information that is facilitated by the corpus callosum is more at the root of the poorer performance IQ scores than the cognitive functions related to the cingulate gyrus. The corpus callosum serves the function of interhemispheric transfer. If it is damaged, processing speed is slowed, thus impacting the performance IQ measures, which have time limits. Therefore, in further investigation of the relationship of the cingulate gyrus and cognitive functioning of individuals with early hydrocephalus, it would be prudent to include measures of memory, special orientation, and executive functions.

In a study of cingulate gyrus atrophy associated with traumatic brain injury, Yount, et al. (2002) found that most of the atrophy was in the posterior cingulate gyrus region, as would be expected in hydrocephalus situations. They were unable to find significant relationships between the atrophy and neuropsychological testing, which included a memory scale. They reasoned that cingulate gyrus has a more indirect role in cognitive and emotional functions than other cortical areas. Additionally, they considered that functionally related regions may serve to compensate for cingulate losses,
therefore preventing direct neurobehavioral sequelae. Therefore, there is the possibility that cingulate gyrus surface areas may not correlate strongly with neuropsychological testing, despite the use of the most appropriate measures.

The corpus callosum, as hypothesized, was significantly smaller in the hydrocephalus group than the control group, whereas the expected differences were not found in the cingulate gyrus areas. These findings suggest support for the hypothesis presented by Fletcher, McCauley, et al. (1996), that white matter may be impacted more than gray matter by hydrocephalus because edema initially affects white matter then, in time, extends to the gray matter. However, Fletcher, McCauley, et al. (1996), found that contrary to their hypothesis, gray matter in the regions assessed was affected to a greater degree than white matter. These results appear contradictory to the present study. However, the earlier research studied four quadrants of the brain in three consecutive transaxial MRI scans, selected from the vertex down. Thus, they studied the centrum semiovale, rather than periventricular white matter. Additionally, the authors noted that some of the decreases in gray matter percentages reflected a loss of neurons with callosal projections. Therefore, it seems to follow that gray matter reductions occur more globally, with the largest concentration of loss in posterior regions, whereas white matter reductions are most prominent regionally, in periventricular areas.

Looking at the specific gray matter and white matter structures in this study, the corpus callosum is in a more vulnerable position in a hydrocephalic brain than the cingulate gyrus. For example, the corpus callosum is immediately inferior to the falx cerebi, which is a prominent fold of dura mater that separates the two hemispheres of the brain (Bigler & Clement, 1997). The cingulate gyri are situated laterally, on either side
of the falx. During a time of ventricular expansion, the corpus callosum can be damaged as it is compressed upward into the falx, whereas the cingulate gyri are relatively more protected. Therefore, it is reasonable to find greater size reductions in corpus callosum surface areas than cingulate gyrus surface areas in hydrocephalus studies.

The participants with hydrocephalus had significantly lower performance and full-scale IQ scores compared to the control participants; however, the depressed verbal IQ scores were not significantly lower. These findings are typical to some studies (Dennis, et al., 1981; Fletcher, Bohan, et al., 1992). However, due to variations in subject groups, some researchers do find significant differences in verbal IQ scores, as well as performance and full-scale (Fletcher, McCauley, et al., 1996; Jacobs, Northam, & Anderson, 2001).

The significant verbal and nonverbal discrepancy that was found in the present study is typical but does not occur in all studies. Jacobs, et al. (2001) did not find this discrepancy and noted that they were not the first to have such results. Although all the patient participants in this study did have a verbal and nonverbal discrepancy, favoring verbal skills, Brookshire, et al. (1995b) had more variation amongst patient participants. They noted that children who are shunted for hydrocephalus do not always reach significant discrepancies and some did not demonstrate a discrepancy at all. Additionally, they found variability in the performance on the measures, including the degree of verbal and nonverbal discrepancy over time. Therefore, it is important to remember that a mean score is a group summary and does not convey individual performance and that individual performance varies at different times of testing.
The present study had several limitations that future studies can overcome. The sample size was small, which limited the power of the study to obtain significant results and the ability to generalize the results. Secondly, only age and gender were available for the participants. Even medical background information was sparse for the hydrocephalus participants. Therefore, the specific etiology of hydrocephalus was not included in the study. Furthermore, testing information in the present study was lacking. There were no records of which specific intelligence test was given to each participant, so the tests were assumed to be equivalent since they are standardized. The female control participants had missing test scores and therefore were removed from some of the analyses, which further limited the study's ability to reach significance. An additional source of variability in the present study was in the MRI scan measures; some were taken every five millimeters, others every seven millimeters. Importantly, there were no total intracranial volume measurements available to correct for brain-size variations. Seeing how the study measured children, who are in the process of growing, this added some measurement error. Lastly, there were several adjustments in the measuring protocol (discussed previously) due to anatomical variations related to hydrocephalus that also increased the amount of error in the calculations.

It is advised that future studies have a larger group of participants with carefully matched controls; matching for age and gender, and perhaps factors such as social-economic status, race, and handedness. Ideally in future studies, the medical background regarding common concerns in the hydrocephalus population can be carefully collected: etiology, age of hydrocephalus onset, number of shunt placements, degree of mobility/paralysis, and so forth. This information allows for subcategorization (in a larger
sample) or helps a researcher to recognize possible confounding health factors. Future studies could use standardized verbal and non-verbal measures, as well as a variety of measures for memory, spatial orientation, and executive functioning to get a better profile of cognitive functioning. As mentioned before, it is advised that verbal and nonverbal measures should be analyzed separately, rather than using a verbal and nonverbal discrepancy score. Whenever possible, studies should use MRI scans that are taken with the same parameters, to reduce error due to various scan parameters. Regional surface area measurements should be taken from multiple slices, perhaps in a plane that is not subject to anatomical variation, such as coronal or axial, instead of sagittal. If possible, volume measurement, rather than surface area measurement is advisable. Lastly, future studies may want to check for differences in right versus left cingulate gyrus, because Fletcher, McCauley, et al. (1996), found varying differences in gray and white matter in the four quadrants that were assessed.
References


Appendix: FIGURES
Figure Headings

Figure 1. A sketch of a sagittal view of the corpus callosum and the anterior commissure. The numbered regions serve to delineate the white matter regions and their corresponding cortical connections (Klaas, et al., 1999) and functions (Funnell, et al., 2000).

Figure 2. A sketch of a sagittal view of the cingulate gyrus, corpus callosum (shaded), and anterior commissure. Clark and Boutros (1999) delineated four regions in the anterior cingulate gyrus and three regions of the posterior cingulate gyrus. The anterior cingulate gyrus consists of Brodmann’s area 24 (B 24), the prelimbic area (PL), the paragenue area (PG), and the infralimbic area (IL). The posterior cingulate gyrus consists of Brodmann’s area 23, the retrosplenial area (RS), and the parasplenial area (PS).

Figure 3. The cingulate gyrus was divided into three regions (based upon Killiany, et al., 2000). The regions are as follows: posterior cingulate gyrus (PC), caudal anterior cingulate gyrus (CAC), and rostral anterior cingulate gyrus (RAC).

Figure 4. The participants with hydrocephalus have a significant discrepancy between the mean verbal IQ and the mean performance IQ, whereas the control participants have very little discrepancy. The table abbreviations are as follows: Hydrocephalus participant mean score (H). Control participant mean score (C).
Figure 1  Corpus Callosum and Anterior Commissure: Topographically Organized

A sketch of a sagittal view of the corpus callosum and the anterior commissure.

The numbered regions serve to delineate the white matter regions and their corresponding cortical connections (Klaas, et al., 1999) and functions (Funnell, et al., 2000).

<table>
<thead>
<tr>
<th>Area</th>
<th>Label</th>
<th>Cortical connection</th>
<th>Function</th>
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<tr>
<td>1</td>
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<td>Inferior premotor</td>
<td></td>
</tr>
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<td>Prefrontal</td>
<td></td>
</tr>
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<td>3</td>
<td>Rostral body</td>
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<td></td>
<td></td>
<td>Supplementary motor</td>
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<td>Motor</td>
<td>Motor</td>
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<tr>
<td>8</td>
<td>Anterior commissure</td>
<td>***</td>
<td>Olfactory</td>
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</table>

A sketch of a sagittal view of the corpus callosum and the anterior commissure.
A sketch of a sagittal view of the cingulate gyrus, corpus callosum (shaded), and anterior commissure. Clark and Boutros (1999) delineated four regions in the anterior cingulate gyrus and three regions of the posterior cingulate gyrus. The anterior cingulate gyrus consists of Brodmann’s area 24 (B 24), the prelimbic area (PL), the paragenue area (PG), and the infralimbic area (IL). The posterior cingulate gyrus consists of Brodmann’s area 23, the retrosplenial area (RS), and the parasplenic area (PS).
The cingulate gyrus was divided into three regions (based upon Killiany, et al., 2000). The regions are as follows: posterior cingulate gyrus (PC), caudal anterior cingulate gyrus (CAC), and rostral anterior cingulate gyrus (RAC).
Figure 4  Verbal and Nonverbal Discrepancy in Hydrocephalus IQ Scores

The participants with hydrocephalus have a significant discrepancy between the mean verbal IQ and the mean performance IQ, whereas the control participants have very little discrepancy.  The table abbreviations are as follows:  Hydrocephalus participant mean score (H).  Control participant mean score (C).

*p < .05.  **p < .01.