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Hydrocephalus status in spina bifida: an evaluation of variations in neuropsychological outcomes

Clinical article

Lyla E. Hampton, M.A.,[1] Jack M. Fletcher, Ph.D.,[1] Paul T. Cirino, Ph.D.,[1] Susan Blaser, M.D.,[2] Larry A. Kramer, M.D.,[6] James Drake, M.B.B.Ch.,[3,5] and Maureen Dennis, Ph.D.[4,5]

[1]Department of Psychology, University of Houston; [6]Department of Diagnostic and Interventional Imaging, University of Texas Health Science Center at Houston, Texas; [2]Department of Diagnostic Imaging, [3]Division of Neurosurgery, and [4]Program in Neuroscience and Mental Health, The Hospital for Sick Children, Toronto; and [5]Department of Surgery, University of Toronto, Ontario, Canada

Object. The effect of hydrocephalus status on neuropsychological outcomes in children with spina bifida (SB) has not been carefully evaluated. The authors hypothesized a stepwise progression of outcomes related to hydrocephalus status (shunt-treated, arrested, or no hydrocephalus) and that motor, spatial, and executive function tasks would be more sensitive to hydrocephalus status than vocabulary and reading tasks.

Methods. Two hundred eight children (mean age 11.2 years) with SB were grouped according to hydrocephalus status: shunt-treated hydrocephalus (166 children), arrested hydrocephalus (18 children), and no hydrocephalus (24 children). Sixty-one typically developing children were included as a control group (mean age 12.05 years). All children were tested across neuropsychological content domains, including verbal and nonverbal IQ, reading and mathematical achievement, explicit memory, visuospatial function, executive function, and motor skills.

Results. There was a stepwise progression of outcomes. Averaging across tasks, performance scores of children with SB and no hydrocephalus (mean standard score 92.60) were higher than those of children with SB and arrested hydrocephalus (mean standard score 86.86), and scores of children in the latter group were higher than those of children with SB and shunt-treated hydrocephalus (mean standard score 82.30). All 3 groups scored lower than the control group (mean standard score 105.94). Fine motor tasks best differentiated the arrested-hydrocephalus and shunt-treated groups. Verbal and executive function tasks, often associated with socioeconomic status, best differentiated the group of children with SB and no hydrocephalus from the control group.

Conclusions. With the exception of fine motor skills and small differences in memory and spatial domains, children with SB and arrested or shunt-treated hydrocephalus have similar neuropsychological profiles. Performance of all 3 groups of children with SB was below that of the control group, which also reflects the lower socioeconomic status of the children with SB. *(DOI: 10.3171/2011.6.PEDS10584)*

Key Words • **hydrocephalus** • **spina bifida** • **meningomyelocele** • **neuropsychology** • **intelligence** • **magnetic resonance imaging**

Neural and cognitive development in children with SB may be compromised not only by the disorder itself, but also by hydrocephalus,[1,11–13,24] which contributes to variability of neuropsychological outcomes.[11,18,29] It is important to understand how hydrocephalus affects outcome in SB, if only because some current approaches to treatment delay shunt implantation in many children.[2]

Since the 1950s, the most common form of treatment for conditions producing hydrocephalus, including SB, has been implantation of a ventricular shunt to divert excess CSF into other body cavities and reduce ventriculomegaly.[5,23] It became routine to undertake shunt placement in most children with myelomeningocele soon after birth,[19,27,33] because early cohorts of children who were not treated with shunting demonstrated progressive intel-

Abbreviations used in this paper: CM-I = Chiari malformation Type I; CM-II = CM Type II; SB = spina bifida; WJR = Woodcock-Johnson psychoeducational battery, revised.

This article contains some figures that are displayed in color online but in black and white in the print edition.

lectual and cognitive decline.[17,30] Shunting of CSF ameliorates functional outcome differences between children with severe hydrocephalus and those with arrested hydrocephalus[33] and improves neuropsychological function in young adults with arrested hydrocephalus.[24]

Knowledge of how hydrocephalus status affects cognitive function is incomplete. Many studies of neuropsychological outcomes include both shunt-treated and non–shunt-treated children within the same group. Some studies have failed to define hydrocephalus status in children who were not treated with shunts; for example, Iddon et al.[20] reported that hydrocephalus (with or without SB) impaired neuropsychological function, but inferred the absence of hydrocephalus from the lack of a diversionary shunt, so it remains possible that some children had arrested hydrocephalus. Children with and without shunts will likely differ in the presence of CM-II, which is reliably associated with the more severe, myelomeningocele form of SB.[28] A more severe presentation of hydrocephalus, usually in association with SB myelomeningocele, likely contributes to greater dysfunction in achievement and neuropsychological skills.[15,25] More specifically, the presence of hydrocephalus is related to lower performance on fine and gross motor skills and visuospatial and perceptual tasks.[10,16] More information is available about cognitive outcome in children with myelomeningocele than in those with milder forms of spinal dysraphisms (such as meningocele or lipoma) or arrested hydrocephalus.

Children with SB and myelomeningocele have areas of characteristic cognitive strengths and weaknesses, likely arising because of impairments in core processes that operate over multiple content domains.[9,15] Areas of strength include the derivation of meaning through learned associations, including word reading and vocabulary. Areas of weakness include the assembly, construction, and representation of information, including coordinate visual perception, spatial construction, language and reading comprehension, mathematical computation, and aspects of memory and executive function.[15]

The present study revisited the relationship between hydrocephalus status (classified as shunt-treated, arrested without CSF shunting, or no hydrocephalus) and neuropsychological outcomes in children with SB. We included participants who underwent shunt placement early in development, as well as participants without shunts who had early ventriculomegaly, and participants with SB and no ventriculomegaly. Although assessment of long-term neuropsychological outcomes in children with arrested versus shunt-treated hydrocephalus cannot resolve treatment questions, it may contribute to the evidence basis for a randomized trial involving different CSF shunting treatments.

The first hypothesis was that hydrocephalus would result in lower performance across content domains, particularly in motor, visuospatial, and executive function areas. The second hypothesis was that, across outcomes, we would observe a stepwise progression, such that children with SB and shunt-treated hydrocephalus would demonstrate poorer neuropsychological performance than the other groups (all other children with SB and the control group); children with SB and arrested hydrocephalus would demonstrate poorer performance than the children with SB and no hydrocephalus; children with SB and no hydrocephalus would demonstrate the best performance of the clinical groups but their performance would be below that of the control group. The third hypothesis involved a group-by-task interaction, such that larger performance differences among groups would be found on spatial, mathematical, memory, motor, and executive function tasks and smaller performance differences would be found on verbal and reading tasks.

Methods

Participants

The sample was derived from a larger sample of 431 children and adolescents with SB and a comparison group of 61 typically developing participants (controls) recruited from 1999 to 2004 for a research project on SB.[14] To eliminate children with intellectual deficiencies, and to clarify patterns of cognitive and academic performance,[10] we required that either the verbal (Vocabulary) or nonverbal (Pattern Analysis) IQ subtest standard score exceed 69 on the Stanford-Binet Intelligence Scale, fourth edition (Stanford-Binet 4).[31] Also, only children with lower-level lesions (below T-12) were selected because few children with arrested or no hydrocephalus have the upper-level spinal lesions, which are more severe and may be qualitatively distinct; 64 children were excluded because they had upper-level lesions.[14] One hundred twenty-seven patients were excluded because they did not meet the age criterion (18 years or younger).

The final sample consisted of 208 children and adolescents with SB and 61 controls. Three groups of children with SB were defined on the basis of either radiological review of MR imaging scans obtained specifically for the study (in 158 cases) or medical records (in 50 cases). Children were included in the arrested-hydrocephalus or no-hydrocephalus group only on the basis of radiological evidence indicating presence or absence of ventriculomegaly (that is, dilation of the lateral, third, or fourth ventricles). Children were included in the arrested-hydrocephalus group if a concurrent MR imaging study or a previous study showed ventriculomegaly.

One hundred sixty-six children in the shunt-treated hydrocephalus group also had myelomeningocele (an additional 32 were eliminated from the intake sample on the basis of the IQ cut-off). Those with SB myelomeningocele and arrested hydrocephalus (15 children) were combined with a small group of children with meningoceles (3 children) to create a sample of 18 children with SB and arrested hydrocephalus. The children with SB and no hydrocephalus (24 children) included 4 with myelomeningocele, 6 with meningocele, 5 with lipomyelomeningocele, 6 with lipomeningocele, and 3 with a lipoma. This third group was included as a comparison group because they would not be expected to have cognitive deficits related to brain function, but were identified as having "spina bifida," had spinal lesions that required surgery and monitoring, and provided ethnicity and socioeconomic status comparisons that are difficult to obtain from "normal" populations.

Children with SB were primarily recruited from clinics at 3 major hospitals: The Spina Bifida Clinic at Texas Children's Hospital, the Shriners Hospital for Children–Houston, and the Hospital for Sick Children in Toronto. In addition, children were identified as potential participants through support groups for parents of children with SB in Houston and Toronto. Participants were recruited continuously from both sites. Based on previous analyses,[14] the Toronto group performed higher on almost all cognitive domains compared with the Houston group. However, the difference in cognitive performance was related to lower socioeconomic status in the Houston cohort, due to the greater representation of low-income Hispanic individuals in Houston compared with Toronto sites.

The study was approved by human study participant review boards at the University of Houston and the Hospital for Sick Children. Written agreement to participate was obtained from parents and older adolescents and verbal assent was obtained from younger children.

Demographic Comparisons

The sample was geographically, ethnically, and economically diverse (by design, not epidemiologically). Table 1 shows the mean age, sex, socioeconomic status, and ethnicity of participants. Each group included children 7–18 years of age, with the average age ranging from 11.20 years of age in the SB no-hydrocephalus group to 12.05 years of age in the control group. Age did not differ by groups ($F[3, 268] = 1.54$, $p = 0.20$). Sex distribution within groups was comparable except that there were more girls (78%) than boys (22%) in the arrested-hydrocephalus group (see Table 1; $\chi^2[3] = 9.42$, $p = 0.024$). There was a significant association between socioeconomic status and hydrocephalus status ($F[3, 265] = 3.45$, $p = 0.017$), reflecting higher socioeconomic status of the children in the control group ($p < 0.05$); the 3 SB groups did not differ significantly. Therefore, socioeconomic status was used as a covariate in the subsequent analyses. There was also a significant difference in ethnicity across SB groups. Because there were too few children in each ethnic group for statistical comparisons, we compared proportions of Hispanic or non-Hispanic (Asian, Caucasian, black, other) ethnicities ($\chi^2[3] = 11.55$, $p = 0.009$). Non-Hispanics were more represented in the control group (89%) than in the shunt-treated (72%), arrested-hydrocephalus (61%), and no-hydrocephalus (58%) groups. However, because ethnicity and socioeconomic status are related, ethnicity differences were captured by the socioeconomic status covariate and therefore ethnicity was not used as an additional covariate.

Neuropsychological Procedures

Each child was individually assessed in a quiet environment by research assistants supervised by experienced neuropsychologists. Vocabulary was measured using the Vocabulary subtest of the Stanford-Binet 4 subtests (scale score).[31] Spatial processing was assessed with the Judgment of Line Orientation test[22] (age-adjusted z score), which requires the child to match the orientation of 2 lines with 2 of 13 lines laid out in a fanlike array. The test battery also included assessment of word recognition (WJR Basic Reading,[34] scale score) and mathematical computation (WJR Calculations,[34] scale score). Executive function was assessed with a measure of concept formation that required the person to sort shapes based on specific characteristics (color, number) (WJR Concept Formation,[34] scale score). Fine motor skill was assessed with a task requiring the child to insert pegs into slots on a board with either the right or the left hand and with both hands simultaneously (Purdue Pegboard,[32] composite of all 3 conditions, age-adjusted z score). Explicit memory represented the first 5 trials of a verbal learning task (CVLT-C,[8] t-score, trials 1–5). Most children were English-speaking, but a small number were evaluated in Spanish using adaptations of tests like the Stanford-Binet or CVLT-C of Spanish versions of the Woodcock-Johnson tests, a practice supported by previous studies.[4,31]

TABLE 1: Demographic characteristics in 61 controls and 208 children with SB stratified by hydrocephalus status*

Characteristic	Controls	Shunt-Treated Hydrocephalus	Arrested Hydrocephalus	No Hydrocephalus
no. of children	61	166	18	24
mean age (yrs)	12.05 ± 2.83	11.20 ± 2.88	11.73 ± 2.73	11.00 ± 3.18
sex†				
M	30 (49)	95 (57)	4 (22)	10 (42)
F	31 (51)	71 (43)	14 (78)	14 (58)
mean SES†‡	44.19 ± 13.32	39.20 ± 14.96	33.14 ± 13.54	37.56 ± 14.08
ethnicity†				
black	4 (7)	12 (7)	3 (17)	1 (4)
Asian	5 (8)	3 (2)	2 (11)	1 (4)
Hispanic	7 (11)	46 (28)	7 (39)	10 (42)
Caucasian	44 (72)	102 (61)	6 (33)	12 (50)
other	1 (2)	3 (2)	0	0

* Values represent numbers of children (%). Means are presented with SDs. Abbreviation: SES = socioeconomic status.
† $p < 0.05$.
‡ Quantified according to the 4-factor index of Hollingshead.

Imaging Procedures

Magnetic resonance imaging scans were obtained on comparable scanners (GE Healthcare) at each site. Three imaging sequences were obtained. The initial series was a sagittal-plane spin-echo T1-weighted localizer, (FOV 24 cm, TR 500 msec, TE 14 msec, 256 × 192 matrix, 3 mm with a 0.3 skip, 2 repetitions). The localizer was followed by 2 whole-brain coronal acquisitions. One series involved 3D fast spin-echo T2-weighted images (FOV 24 cm, TR 4000 msec, TE 102 msec, ETL 16, 256 × 256 matrix, 1 repetition with contiguous 1.7 mm coronal images). The other was a 3D-spoiled gradient-echo sequence with contiguous 1.7 mm coronal images (FOV 24 cm, TR 18 msec, TE 3 msec, flip angle 25°, 124 locations, 256 × 256 matrix, 1 repetition). Separate T1 and T2 acquisitions were necessary to ensure adequate estimation of CSF versus gray and white matter, essential for quantitative analysis. Conventions for qualitative coding of scans (for children in the SB groups and the control group) were developed and implemented by radiologists in Houston and Toronto blinded to group assignment. The coding system included an overall rating of hydrocephalus (shunt-treated, arrested, none) and severity (mild, moderate, severe). In addition, the lateral, third, and fourth ventricles were separately coded.

Results

Clinical Markers

Table 2 describes clinical markers commonly used to characterize children with hydrocephalus. Because the control group does not, by definition, have impairment on clinical markers, it was not included in these analyses. In brief, groups with hydrocephalus are comparable on demographic and medical complication variables that may impact outcomes, and they differ in ways that would be expected.

We found no statistically significant difference between SB groups (shunt-treated hydrocephalus, arrested

TABLE 2: Clinical characteristics classified in 208 children with SB stratified by hydrocephalus status*

Clinical Markers†	Shunt-Treated Hydrocephalus	Arrested Hydrocephalus	None
no. of children	166	18	24
mean birthweight in g (204 pts)	3278.04 ± 614.03	3193.29 ± 755.49	3350.58 ± 541.91
mean gestational age in wks (190 pts)	38.97 ± 2.43	39.73 ± 1.10	39.32 ± 1.46
ambulatory status‡ (207 pts)			
normal	2 (1)	3 (17)	6 (25)
impaired	41 (25)	9 (50)	14 (58)
w/ support	73 (44)	5 (28)	4 (17)
unable to walk	49 (30)	1 (6)	0
bladder function (205 pts)			
yes	8 (5)	1 (6)	4 (17)
no	156 (95)	17 (94)	19 (83)
seizures (202 pts)			
yes	5 (3)	0	0
in the past	27 (17)	2 (12)	1 (4)
none	129 (80)	15 (88)	23 (96)
oculomotor disorder (203 pts)			
yes	50 (31)	3 (17)	3 (13)
no	111 (69)	14 (83)	21 (88)
no. of shunt revisions (165 pts)			
none	42 (25)	—	—
1	49 (30)	—	—
2–4	56 (34)	—	—
5–9	15 (9)	—	—
10+	3 (2)	—	—
history of shunt complication (119 pts)			
obstruction	78 (66)	—	—
infection	8 (7)	—	—
both	17 (14)	—	—
other	16 (13)	—	—

* pts = patients.
† Numbers of patients specified per category are the number for whom data were available.
‡ $p < 0.05$.

hydrocephalus, and no hydrocephalus) with respect to birth weight ($F[2, 203] = 0.32$, $p = 0.72$) or gestational age ($F[2, 189] = 0.93$, $p = 0.40$). As expected, ambulatory status varied by SB group ($\chi^2[6] = 52.21$, $p < 0.0001$). The majority of patients in the shunt-treated hydrocephalus (99%), arrested hydrocephalus (86%), and no hydrocephalus groups (68%) had impaired ambulation, with the expected stepwise progression of impairment. Patients in the 3 groups had the expected urological difficulties, but the between-group differences were not statistically significant ($\chi^2[2] = 5.33$, $p = 0.07$). There were no significant differences in seizure history ($\chi^2[4] = 4.32$, $p = 0.36$) or reports of vision problems ($\chi^2[2] = 4.78$, $p = 0.092$). Of children with shunt-treated hydrocephalus, 55% had a history of 2 or fewer shunt revisions, 34% had 3–4 revisions, and 11% had more than 5 shunt revisions. Most children with shunt-treated hydrocephalus (66%) had a history of obstruction; other complications included infection (in 7%), both infection and obstruction (in 14%), or other complications (in 13%).

Imaging Abnormalities

Magnetic resonance imaging features were compared between the shunt-treated hydrocephalus, arrested-hydrocephalus, and no-hydrocephalus groups (Table 3). Some levels of these characteristics were combined when the sample sizes were small. Significant group differences were noted for Chiari malformations ($\chi^2[6] = 139.89$, $p < 0.001$). Type II Chiari malformations were present in 93% of the shunt-treated group; only 3% of patients in this group had CM-I and another 3% had no CM. The arrested-hydrocephalus group was mainly composed of children without CM (56%) or with CM-I malformations (31%); only 13% of children in this group had CM-II. The no-hydrocephalus group had the highest percentage of patients without CM (84%). Significant group differences were found for corpus callosum status ($\chi^2[4] = 96.26$, $p < 0.0001$). The corpus callosum of children in the shunt-treated group was likely to be hypoplastic (48%) or dysgenetic (47%). Children in the arrested-hydrocephalus group were likely to present with hypoplasia (64%) and children in the no-hydrocephalus group more often had a normal corpus callosum (82%). Significant intergroup differences were found with respect to tectal dysmorphology ($\chi^2[2] = 47.68$, $p < 0.0001$); 79% of the shunt-treated subgroup presented with tectal dysmorphology in comparison with 33% of the arrested-hydrocephalus group and 0% of the no-hydrocephalus group.

Comparisons of blind radiological review of MR imaging indicators of hydrocephalus between the shunt-treated and arrested-hydrocephalus groups revealed several differences in the presentation of hydrocephalus ($\chi^2[1] = 10.74$, $p = 0.001$), supporting the classification of children with arrested hydrocephalus. Hydrocephalus at time of MR imaging was noted in 51% of the shunt-treated group compared with 100% of the arrested-hydrocephalus group. The type of hydrocephalus in the shunt-treated patients was more likely to be indeterminate (55%) or obstructive (41%) than ex vacuo (5%); in the arrested-hydrocephalus group, the type of hydrocephalus was primarily coded as indeterminate (83%) and ex vacuo (17%) ($\chi^2[2] = 8.48$, $p = 0.014$). Severity of hydrocephalus did not differentiate the groups ($\chi^2[2] = 1.07$, $p = 0.59$). Hydrocephalus was mild (67%) or moderate (33%) in the arrested-hydrocephalus group and mild (78%) or moderate (21%) for the shunt-treated subgroup as well; there was 1 patient with severe hydrocephalus in the shunt-treated group. The lateral ventricles of children in the shunt-treated group were more likely to be enlarged (49%) or normal (39%) than small (12%). All children in the arrested-hydrocephalus group presented with enlarged ventricles ($\chi^2[2] = 11.54$, $p = 0.0031$). Third ventricles were normal (54%) or enlarged (30%) rather than small (16%) in children in the shunt-treated group. Children in the arrested-hydrocephalus group more often had enlarged (64%) or normal (36%) third ventricles ($\chi^2[2] = 7.26$, $p = 0.027$). The fourth ventricle was generally small (89%) in children with shunt-treated hydrocephalus compared with the normal (50%) and small (50%) fourth ventricles in children with arrested hydrocephalus ($\chi^2[2] = 19.66$, $p < 0.0001$).

Neuropsychological Outcomes

All scores were transformed to standard scale scores (mean 100, SD 15) to facilitate examination of performance across cognitive domains. There was a small amount of missing data for individual tests and socioeconomic status; to avoid losing rare cases, the mean of the subgroup was imputed. To examine the effect of hydrocephalus status on performance across domains, a multivariate approach to repeated-measures ANOVA was run using SAS Proc GLM. The between-subjects factor was the hydrocephalus status group and the within-subjects factor was the mean standard score for each task, representing performance across domains. We included socioeconomic status (SES) as a covariate, and preliminary analyses evaluated the interaction of SES with group and task. The 3-way hydrocephalus status × task × SES interaction was not statistically significant ($F[18, 724] = 1.231$, $p = 0.23$). Because the SES × task interaction ($F[6, 256] = 1.77$, $p = 0.11$) and the SES × group interaction ($F[3, 261] = 0.81$, $p = 0.49$) were also not significant, socioeconomic status was retained as a covariate for further analysis, but interactions with socioeconomic status were trimmed from the model. Because all pairwise comparisons were examined in the hydrocephalus status grouping, Tukey pairwise comparisons were completed to maintain the familywise error rate ($\alpha FW = 0.05$). Effect sizes were measured using the raw means and pooled SD across the 2 groups being compared using Cohen's d.[26] Statements of linear contrast determined the order of performance in each analysis.

The first hypothesis was that hydrocephalus would reduce performance across neuropsychological content domains, particularly in motor, visuospatial, and executive function. As seen in Fig. 1, the mean performance scores for both hydrocephalus groups (shunt-treated and arrested) were lower than the mean performance scores of the control group across all neuropsychological domains, particularly in verbal, spatial, executive function, and memory. The verbal and executive function scores in the no-hydrocephalus group were lower than those of the control group.

TABLE 3: Qualitative abnormalities found via MR imaging in 208 children with SB stratified by hydrocephalus status*

MRI Abnormality	Shunt-Treated Hydrocephalus	Arrested Hydrocephalus	No Hydrocephalus
CM† (188 pts)			
absent	4 (3)	9 (56)	19 (100)
other	3 (2)	0	0
CM-I	4 (3)	5 (31)	0
CM-II	142 (93)	2 (13)	0
corpus callosum† (158 pts)			
normal	7 (5)	4 (29)	0
dysgenetic	60 (47)	1 (7)	0
hypoplastic	61 (48)	9 (64)	0
tectal dysmorphology† (157 pts)			
yes	100 (79)	5 (36)	0
no	27 (21)	9 (64)	16 (100)
hydrocephalus† (140 pts)			
absent	63 (49)	0	—
present	65 (51)	12 (100)	—
if hydrocephalus present† (76 pts)			
secondary to SB	26 (41)	0	—
ex vacuo	3 (5)	2 (17)	—
indeterminate	35 (55)	10 (83)	—
if hydrocephalus present† (75 pts)			
mild	49 (78)	8 (67)	—
moderate	13 (20)	4 (33)	—
severe	1 (2)	0	—
lat ventricles† (139 pts)			
normal	50 (39)	0	—
small	15 (12)	0	—
enlarged	62 (49)	12 (100)	—
3rd ventricle (142 pts)			
normal	69 (54)	5 (36)	—
small	20 (16)	0	—
enlarged	39 (30)	9 (64)	—
4th ventricle† (142 pts)			
normal	11 (9)	7 (50)	—
small	114 (89)	7 (50)	—
enlarged	3 (3)	0	—

* Numbers of patients in parentheses.
† $p < 0.05$.

The second hypothesis predicted a stepwise order of outcome (shunt-treated hydrocephalus group < arrested hydrocephalus group < no-hydrocephalus group < controls). As seen in Fig. 2, which collapses results across tasks, the average pattern across each group was consistent with the pattern predicted in the second hypothesis. Linear contrasts were significant for all tests ($p < 0.0001$). Among the children with SB, those in the no-hydrocephalus group performed at the highest level (mean standard score 92.60), and those in the arrested-hydrocephalus group performed better (mean 86.86) than those in the shunt-treated hydrocephalus group (mean 82.30), with all 3 groups showing lower group averages than the controls (mean 105.94).

The hydrocephalus-group–by-task interaction was consistent with the third hypothesis ($F[18, 736] = 3.43$, $p < 0.0001$), suggesting that the pattern of group differences varies depending upon the domain of cognitive performance. Figure 1 shows the pattern of group differences for each separate task on all of the variables. Overall mean performance scores were compared between groups for each separate cognitive domain.

Tukey post hoc analyses were performed to evaluate all pairwise comparisons for each task, with the α level set to 0.0125 to control for multiple tests. The results were generally consistent with the second hypothesis (Fig. 1). The performance of the shunt-treated group was signif-

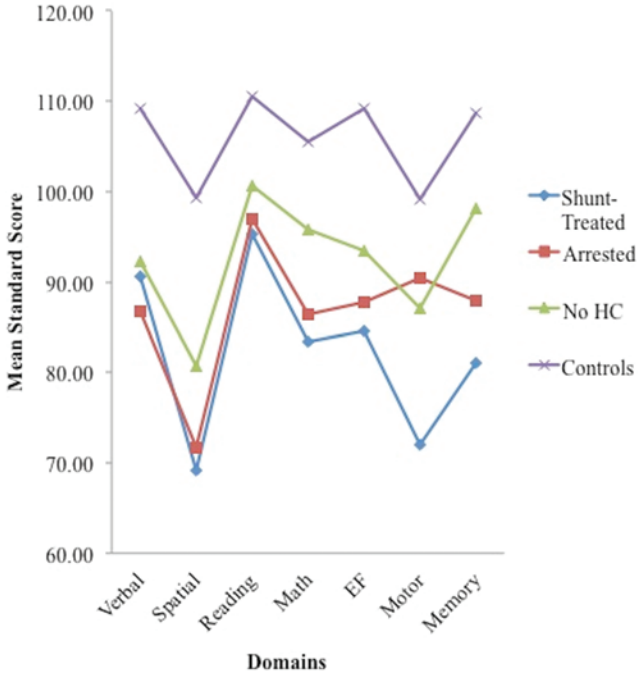

Fig. 1. Mean performance across neuropsychological domains for children with SB grouped by hydrocephalus status and a control group of typically developing children. EF = Executive Function; HC = hydrocephalus.

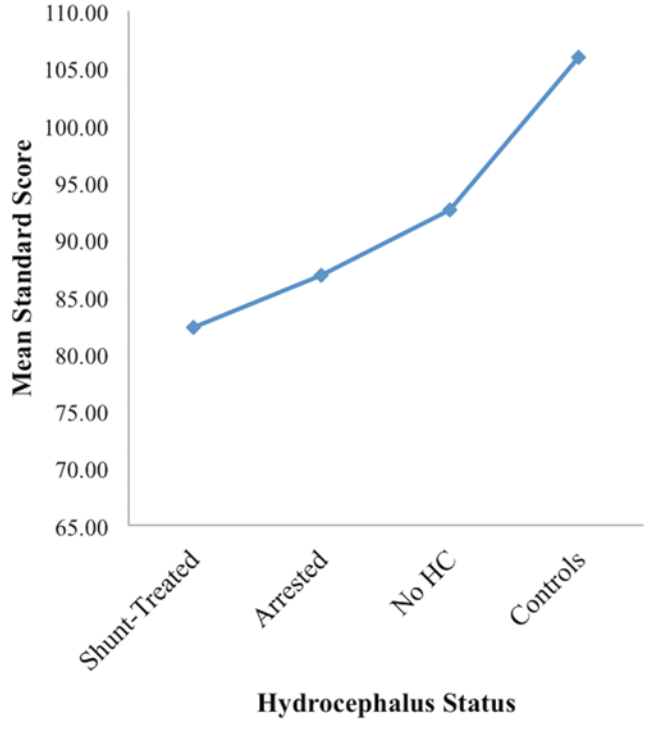

Fig. 2. Linear order of overall performance across tasks for children with SB grouped by hydrocephalus status and for the control group.

icantly poorer than that of the control group across all tasks ($p < 0.0125$). The performance of the arrested-hydrocephalus group differed significantly from that of the control group on vocabulary, spatial, executive function, and memory tasks, but not on the other tasks. Differences between the no-hydrocephalus and control groups were significant only for vocabulary and executive function tasks; children with SB without hydrocephalus performed similarly to controls across the remaining domains.

Among children with SB, the shunt-treated and arrested-hydrocephalus groups differed only on the fine motor task, whereas the shunt-treated and no-hydrocephalus groups differed only on motor and memory tasks, with the shunt-treated group showing weaker performance in both domains. The arrested-hydrocephalus and no-hydrocephalus groups did not differ significantly from each other on any task. For the most part, the performance patterns of the arrested-hydrocephalus and shunt-treated groups were similar, with less impairment in the arrested group in motor and memory domains. Hydrocephalus may disrupt performance in certain domains (for example, motor function) more than in others.

Given the small sizes of several groups, power for α-corrected follow-up tests can be reduced, so group differences were further examined using effect-size statistics (Table 4). As expected, the effect sizes were large when comparing the shunt-treated and control groups across all domains. The effect sizes were also large when comparing the arrested-hydrocephalus and control groups across vocabulary, spatial, executive function, and memory domains. Effect sizes were large when comparing the no-hydrocephalus and control groups on executive function and vocabulary tasks. These results again demonstrate the predicted stepwise pattern in terms of number of affected domains (in comparison with the control group) from the shunt-treated group to the arrested-hydrocephalus group to the no-hydrocephalus group. When comparing the shunt-treated and arrested-hydrocephalus groups, the effect size was large on a memory task, as was the effect size when comparing the shunt-treated and no-hydrocephalus groups across motor and memory tasks. Effect sizes were small when comparing the arrested-hydrocephalus and no-hydrocephalus groups.

A set of analyses compared neuropsychological outcomes within the shunt-treated group according to hydrocephalus status (Table 3). No significant differences were found ($p > 0.20$) for comparisons of outcomes (group × task) on variables involving presence or type of hydrocephalus, severity, and lateral, third, and fourth ventricle status. No significant differences were found ($p > 0.20$) in a final set of analyses that compared neuropsychological outcomes within the shunt-treated group according to shunt revision and history of shunt infection, thus justifying treating the shunt-treated children as a single group.

Discussion

An ongoing medical debate concerns the risks and benefits of CSF shunting in children with less severe hydrocephalus presentations and the utility of options such as endoscopic third ventriculostomy and monitoring with serial neuroimaging.[2,6,7,30] Although our retrospective study cannot address the question of medical care, it does provide data on long-term cognitive and academic outcomes in 3 key groups: children with myelomeningo-

TABLE 4: Effect size by hydrocephalus status across domain

Domain	Controls vs Shunt-Treated Hydrocephalus	Controls vs Arrested Hydrocephalus	Controls vs No Hydrocephalus	Shunt-Treated Hydrocephalus vs Arrested Hydrocephalus	Shunt-Treated Hydrocephalus vs No Hydrocephalus	Arrested Hydrocephalus vs No Hydrocephalus
verbal	1.12*	1.53*	1.06*	0.23	−0.10	−0.34
spatial	1.28*	1.72*	1.03	−0.46	−0.45	−0.40
reading	0.81*	0.80	0.58	−0.08	−0.27	−0.16
math	1.08*	1.02	0.61	−0.13	−0.53	−0.42
executive function	1.48*	1.42*	1.09*	−0.19	−0.52	−0.43
motor	1.61*	0.54	0.84	−1.04*	−0.88*	0.20
memory	1.76*	1.52*	0.83	−0.41	−1.04*	−0.66

* $p < 0.0125$.

cele and CM-II who have undergone shunt placement; children with SB and ventriculomegaly who have not undergone shunt placement, and children with SB but no clinical hydrocephalus. The study is unique because all children were seen in the developmental period and era when CSF shunting was routinely performed in patients with SB meningomyelocele.

As expected, neuropsychological performance was poorer in the clinical groups than in the control group. Consistent with the hypothesis that performance would reflect a stepwise pattern of hydrocephalus severity and treatment, the group with no hydrocephalus and little evidence of significant brain anomalies performed better than the arrested-hydrocephalus group, which, in turn, outperformed the shunt-treated group, which differed significantly from the control group on all tasks. Furthermore, a hydrocephalus status–by–content-domain interaction among children with SB was demonstrated: The difference between the performance children with shunt-treated or arrested hydrocephalus and that of controls was greater on spatial, executive function, fine motor, and explicit memory tasks than on vocabulary and word reading tasks.[9,16] Our hypothesis was supported in general by separate post hoc comparisons between groups on each individual task, as well as by effect size analyses.

Although the pattern of group differences between the controls and the SB groups was similar and large for both spatial and vocabulary tasks across all hydrocephalus-status subgroups, these particular results are complicated by the level of performance, which was clearly higher for vocabulary than for spatial tasks (Fig. 1). Notably, this pattern was also apparent for the control group, whose vocabulary was in the high-average range, with the performance of the SB groups near the average range, a result consistent with previous research.[3,25,30] The uniformly low performance on the spatial task may also reflect the less-than-adequate normative sample of the Judgment of Line Orientation task, particularly relative to the vocabulary measure from the Stanford-Binet 4.

The configuration of the SB group differences is informative. The arrested-hydrocephalus group generally performed more like the shunt-treated group than the no-hydrocephalus group, a comparison tempered by the absence of upper-level spinal lesions in the shunt-treated group. In addition, the children in the arrested-hydrocephalus group all had ventriculomegaly on radiological review; this was more variable in the shunt-treated group. Only 1 child had severe hydrocephalus in either arrested-hydrocephalus or shunt-treated groups. However, outcomes within the arrested-hydrocephalus and shunt-treated groups did not vary based on residual hydrocephalus. No significant group differences (arrested vs shunt-treated vs no hydrocephalus) were apparent in vocabulary and spatial domains, the executive function domain, or in achievement domains related to reading and mathematical calculation. The difference between the no-hydrocephalus and shunt-treated groups with respect to explicit memory was small. Fine motor performance, the clearest differentiator of the 3 groups, was especially impaired in the shunt-treated group (Table 4). Children without hydrocephalus, and those with arrested hydrocephalus, tended to show better fine motor skill outcomes compared with the shunt-treated group.

That fine motor skills differentiated arrested and shunt-treated hydrocephalus is of some interest. Cerebellar dysmorphologies impair motor regulation.[9] The shunt-treated group had a high incidence of CM-II malformation of the cerebellum and hindbrain (Table 3), and many in the arrested-hydrocephalus group also had cerebellar impairments on MR imaging (Table 3), but the arrested-hydrocephalus group had the better motor function. Either these tasks require less cerebellar involvement than others or the fine motor deficit is one of degree (the arrested group had an effect size of 0.53, which was not negligible but was not significant at $p < 0.01$). Hydrocephalus thins white matter,[6,21] which may contribute to fine motor deficits, although this of itself would not explain why fine motor skills of the arrested-hydrocephalus and control groups did not differ. The arrested-hydrocephalus and no-hydrocephalus groups did not differ from each other or from controls.

For executive function, all 3 SB groups (shunt-treated, arrested-hydrocephalus, and no hydrocephalus) differed significantly from the control group but not from each other (Table 4). In contrast to other domains, effect sizes were small to moderate among SB groups, so that executive function contributed less robustly to group differentiation. The patients with shunt-treated hydrocephalus performed in the below-average range and may be impaired on this aspect of executive function. It is not clear

how this finding aligns with the literature. In suggesting that executive functions are especially impaired in children with SB and shunt-treated hydrocephalus, Iddon et al.[20] used measures of executive functions that required greater spatial processing and motor speed demands than those used in the present study, where spatial and fine motor deficits were most salient. Measures of cognitive domains with fewer motor requirements (for example, explicit memory, spatial cognition) were more sensitive to the effects of hydrocephalus (that is, more and larger group differences were noted) relative to measures of executive function.

The limitations of the study include the smaller sample size for the arrested-hydrocephalus and no-hydrocephalus groups and the lack of experimental and clinical tests of cognitive and motor functions. The use of prospective imaging from birth in all participants to reduce reliance on MR imaging studies obtained several years after shunting decisions and historic medical record information would have improved the study.

Conclusions

Despite these considerations, this study provides the new comparative information that children with arrested hydrocephalus do have compromised outcomes, although they perform at higher levels than children with shunt-treated hydrocephalus and major brain malformations, which is information that could provide part of the knowledge base to support future randomized clinical trials on the effects of CSF shunting.[2]

Disclosure

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Address correspondence to: Lyla E. Hampton, M.A., Department of Psychology, University of Houston Texas Medical Center Annex, 2151 West Holcombe Boulevard, Suite 222, Houston, Texas 77204-5053. email: lelmessi@gmail.com.