

# Math and Numeracy in Young Adults With Spina Bifida and Hydrocephalus

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The developmental stability of poor math skill was studied in 31 young adults with spina bifida and hydrocephalus (SBH), a neurodevelopmental disorder involving malformations of the brain and spinal cord. Longitudinally, individuals with poor math problem solving as children grew into adults with poor problem solving and limited functional numeracy. As a group, young adults with SBH had poor computation accuracy, computation speed, problem solving, and functional numeracy. Computation accuracy was related to a supporting cognitive system (working memory for numbers), and functional numeracy was related to one medical history variable (number of lifetime shunt revisions). Adult functional numeracy, but not functional literacy, was predictive of higher levels of social, personal, and community independence.

In modern society, skill in understanding and manipulating numbers is crucial for everyday situations (McCloskey & Macaruso, 1995): We use numbers to follow road signs, to make purchases, to make dates, to follow instructions, to understand the weather, and to take prescriptions. Difficulties with functional numeracy in

young adults are likely to limit academic achievement, functional independence, and vocational success. What is not clear is whether childhood math difficulties, which are common in neurodevelopmental disorders such as spina bifida myelomeningocele with hydrocephalus (SBH), evolve into adult innumeracy and thereby limit later academic, functional, and vocational attainments.

The question of the developmental stability of childhood math problems is pertinent to the functional outcome for young adults with SBH. Children with SBH have poor math skills, and young adults with SBH have limited physical and social independence (e.g., Castree & Walker, 1981; Hayden, Davenport, & Campbell, 1979; Hetherington, Dennis, Barnes, Drake, & Gentili, 2002; Hunt, 1990; Kennedy et al., 1998; Morgan, Blackburn, & Bax, 1993; Stellman-Ward, Bannister, & Lewis, 1993). It is not known whether math and numeracy play a role in functional independence for young adults with SBH.

SBH is a neurodevelopmental disorder involving malformations of the brain and spinal cord. The malformations of the spine involve a failure of neural tube closure, with resulting loss of sensory and motor function below the level of the spinal lesion. The dysmorphologies of the brain involve abnormal formation and maturation of the cerebellum, midbrain, corpus callosum, and posterior brain regions (Fletcher et al., 1992; Fletcher, Dennis, & Northrup, 2000). The hydrocephalus commonly associated with spina bifida involves enlarged cerebral ventricles arising from an imbalance in cerebrospinal fluid biomechanics, as well as a range of primary and secondary effects on the brain (reviewed in del Bigio, 1993; Fletcher et al., 2000).

The modal cognitive profile of school-aged children with SBH includes good word decoding skills (Barnes & Dennis, 1992) and poor math skills on both written and mental computation tasks (Fletcher, Brookshire, Bohan, Brandt, & Davidson, 1995; Friedrich, Lovejoy, Shaffer, Shurtleff, & Beilke, 1991; Halliwell, Carr, & Pearson, 1980; Shaffer, Friedrich, Shurtleff, & Wolf, 1985; Tuleya-Payne, 1983; Wills, 1993; Wills, Holmbeck, Dillon, & McLone, 1990). Poor math skills have been described in SBH children who are neither intellectually impaired nor reading disabled; further, math skills are poorer than reading skills in SBH groups (Fletcher et al., 1995).

Recent research has attempted to characterize the math profile of school-aged children with SBH and to understand the nature of their developmental difficulty with numbers (Barnes et al., 2002). Children with SBH who have good reading decoding skills were found to have relative strengths on math tasks involving basic number knowledge, exact measurement, and some arithmetic operations, and relative weaknesses on tasks of geometry, mental computation, and applied math skills such as estimation and problem solving; further, SBH and control children made similar numbers of math fact retrieval and visual-spatial errors to controls when solving written subtraction problems, although the SBH group exhibited less mature knowledge of arithmetic procedures such as how to borrow from zero.

Developmental math disability has been studied in children with no explicit brain dysmorphology or brain injury. These studies have identified deficits in both the operations used to perform math tasks (e.g., counting) and the cognitive skills that support these operations (e.g., working memory, the cognitive processing that retains information in a form that is accessible and so suitable for carrying out tasks with a mental component; Cowan, 1999).

Children with difficulties in math have problems with the retrieval of math facts and with the development and use of math procedures. Poor phonological working memory, associated with failure to learn, automatize, and retrieve math facts, has been proposed as the basis of deficits in both math and reading for children with comorbid reading and math disability (Conway & Engle, 1994; Geary, 1993). Children with math disabilities, especially those without a comorbid reading disability, use immature procedures (e.g., counting both addends starting from 1 rather than stating the larger addend and counting on the value of the smaller addend) more often and at later ages in solving arithmetic problems (Barrouillet, Fayol, & Lathulière, 1997; Geary, 1990, Gross-Tsur, Manor, & Shalev, 1996; Jordan, Levine, & Huttenlocher, 1995; Jordan & Montani, 1997; Ostad, 1997, 1998). Working memory appears to be poor in children with math disability, and different aspects of working memory may be deficient depending on the presence of a comorbid reading disability (Hitch & McAuley, 1990; Siegel & Ryan, 1989).

The math profile of children with SBH appears similar in some respects to that of children with specific math disability. For one thing, it is not associated with comorbid reading disability (Barnes et al., 2002) and, for another, it is characterized by procedural rather than fact retrieval errors. To be sure, little is known about math skills in young adults with SBH. Some longitudinal stability for poor math is suggested by the observation that Wechsler IQ subtest Arithmetic scores (but not Information, Similarities, or Vocabulary subtests) are poorer than age expectations in older adolescents (mean age 18) with spina bifida (Hommet et al., 1999).

There are several reasons for investigating math in young SBH adults. It is important to establish the following: whether SBH math deficits in childhood are developmentally stable, that is, whether they involve a developmental lag that resolves, or, alternatively, a deficit that persists into adulthood; whether childhood math status and lifetime medical history predict math skill in adulthood; and whether adult math status, whether good or poor, is related to adult functional capacities and quality of life (i.e., whether poor math contributes to the documented problems of young SBH adults with physical and social independence, Castree & Walker, 1981; Hayden et al., 1979; Hetherington et al., 2001; Hunt, 1990; Kennedy et al., 1998; Morgan et al., 1993; Stelman-Ward et al., 1993).

At present, nearly all of the important questions about math in young SBH adults are unanswered. Some specific questions include the following: the status of

computation and problem-solving skills, the level of functional numeracy, whether math computation skill is related to numerical working memory, the longitudinal stability of math deficits, whether medical history variables (such as level of spinal cord lesion and number of shunt revisions) moderate the level of adult math skill, and the implications of poor math for level of functional independence. We studied these specific questions in young adults with SBH:

1. **Math and Numeracy**—We compared computation accuracy, computation speed, problem solving, and functional numeracy in a young adult SBH group to age norms, and made within-group comparisons of reading decoding and math, and functional literacy and functional numeracy. We hypothesized that (a) young adults with SBH would have poorer math and numeracy than age norms, in keeping with the finding of poor math problem solving in adolescents with SBH; and that (b) the lack of comorbidity in reading and math is developmentally stable, so that, within the young adult SBH group, math scores would be lower than reading decoding scores, and functional numeracy would be lower than functional literacy scores.

2. **Numerical Working Memory**—We hypothesized that (a) in comparison to age norms, young adults with SBH would have poorer numerical working memory, but not poorer immediate memory for numbers; and that (b) computation would be associated with working memory.

3. **Longitudinal Stability**—We compared childhood math function with adult math skills and numeracy in individuals for whom both child and adult math scores could be obtained. We hypothesized that poor childhood math would be longitudinally stable, that is, poorer childhood math skills would develop into poorer adult math and a lower level of functional numeracy.

4. **Shunt Revisions And Physical Phenotype**—Individuals with SBH vary in the extent to which their shunt treatment is effective. Throughout the life span, shunts may become blocked, infected, broken, or simply insufficient for growth, and thereby require neurosurgical procedures for revision or replacement. During childhood, the number of shunt revisions has not consistently been linked to cognitive outcome (Fletcher et al., 2000). The cognitive phenotype involving upper spinal lesions has been linked to a variety of more negative cognitive outcomes in childhood than that involving lower spinal lesions (e.g., Friedrich et al., 1991). We hypothesized that math outcome would be unrelated to the number of shunt revisions within a young adult SBH group, but that higher spinal lesions (as opposed to lower spinal lesions) would be associated with poorer adult math.

5. **Numeracy, Literacy, and Perceived Independence**—We hypothesized that young adults with SBH would have lower levels of self-rated independence than age norms, and that both numeracy and literacy would contribute to perceived independence.

## METHOD

### Participants

Participants were 31 young adults with SBH (Mean age 26.9,  $SD = 5.0$ , range 18.5–36.3; 15 women, 16 men; 25 right-handers, 6 left-handers). Each participant had been treated for hydrocephalus with diversionary shunts shortly after birth or in early infancy. Each had adult Verbal and/or Performance IQ scores of 70 or above on the adult Wechsler scales (Mean Verbal IQ 95.4,  $SD = 9.1$ , range 79–114; Mean Performance IQ 85.2,  $SD = 10.2$ , range 70–114). On the basis of childhood Wechsler Intelligence Scale for Children Arithmetic scaled scores, available for 23 young adults, participants were divided into Math Intact ( $N = 15$ , age percentiles  $> 25$ ) and Math Impaired ( $N = 8$ , age percentiles 0–25) groups.

Medical information on SBH participants was obtained by reviewing hospital charts or by direct inquiry. The number of shunt revisions (Mean 9.1,  $SD = 18.1$ , range 0–100) was established by direct questioning of participants and/or parents, and confirmed by medical chart review. Two shunt revision groups were created, one ( $N = 17$ ) whose members had had zero to three revisions, and one ( $N = 14$ ) whose members had had four or more revisions.

The neural tube closes in successive stages and at multiple sites, two of which fail to close in spina bifida, an upper closure site 1, and a lower closure site 5 (Van Allen et al., 1993). From birth records and medical charts, two spinal lesion level groups were created, one ( $N = 8$ ) with upper lesions (lumbar level 1 [L1] and above, corresponding to Van Allen's closure site 1), and one ( $N = 23$ ) with lower lesions (lumbar level 2 [L2] and below, corresponding to Van Allen's closure site 5). One individual's records noted only an upper lumbar spinal lesion, on the basis of which she was assigned to the upper spinal lesion group.

### Tasks

*Computation accuracy and computation speed.* The Math Calculations subtest of the Microcog™ Assessment of Cognitive Function (Powell et al., 1993), presents participants with visual displays of computation problems on a computer screen (e.g.,  $356 + 78$ ;  $754 - 469$ ;  $345 \times 7$ ;  $272 \div 8$ ). Responses are entered on the numeric keypad of the computer. The task requires math fact retrieval, as well as the application of mental procedures such as borrowing and carrying. Scores (number of correct calculations; average response time for correct and incorrect calculations) are expressed as age-based and education-adjusted standard scores ( $M = 10$ ,  $SD = 3$ ).

*Problem-solving accuracy.* In the Arithmetic subtest of the Wechsler Adult Intelligence Scale–Revised (Wechsler, 1981), participants are presented

with oral math problems and provide an oral response. Scores (number of correct responses) are expressed as age-based standard scores ( $M = 10$ ,  $SD = 3$ ).

*Reading decoding.* The Letter–Word Identification task (Woodcock, 1991) requires participants to decode single written words (e.g., when, fixed, distance, preyed, therapeutic). Scores are expressed as age-based standard scores ( $M = 100$ ,  $SD = 15$ ).

*Immediate memory capacity and immediate memory speed.* In the Numbers Forwards subtest of the Microcog™ Assessment of Cognitive Function (Powell et al., 1993), participants reproduce digit sequences (from string lengths of 2 to string lengths of 9) on the numeric keypad of the computer. The sequences appear on a screen sequentially, for 1 sec. Scores (highest memory span, i.e., the highest number of digits recalled, and average response time for correct and incorrect number sequences) are expressed as age-based and education-adjusted standard scores ( $M = 10$ ,  $SD = 3$ ).

*Working memory capacity and working memory speed.* In the Numbers Reversed subtest of the Microcog™ Assessment of Cognitive Function (Powell et al., 1993), participants reproduce visually presented digit sequences on the numeric keypad of the computer in reverse order of presentation. Because digits must be held in memory and manipulated to be retrieved in reverse order, the task is one of working memory. Scores (highest memory span; average response time for correct and incorrect number sequences) are expressed as age-based and education-adjusted standard scores ( $M = 10$ ,  $SD = 3$ ).

*Functional numeracy.* The Arithmetic Skills of the Kaufman Functional Academic Skills Test (Kaufman & Kaufman, 1994) evaluates functional numeracy, the use and understanding of numbers applied to everyday situations and life tasks that involve math competence: making price comparisons, time concepts, banking, adding and subtracting the value of coins, earning money, taking trips by car or taxi, and budgeting. Participants are asked questions about the number information in a visual stimulus such as a graph, numerical symbol, picture, advertisement, or pie chart; for example, looking at a histogram, they are asked how many more of something is contained in the “A” versus “B” bars of the histogram. Scores are expressed as age-based standard scores ( $M = 100$ ,  $SD = 15$ ).

*Functional literacy.* The Reading Skills of the Kaufman Functional Academic Skills Test (Kaufman & Kaufman, 1994) evaluates functional literacy, the use and understanding of written words and signs applied to everyday situations and life tasks that involve reading competence. Skills assessed include the ability to

recognize and understand simple directions, signs, pictorial rebuses, labels, newspaper and magazine articles, recipes, advertisements, abbreviations, and catalog information. Some items are presented in isolation, whereas others appear in their familiar context. Scores are expressed as age-based standard scores ( $M = 100$ ,  $SD = 15$ ).

*Functional independence.* The Scales of Independent Behavior–Revised (Bruininks, Woodcock, Weatherman, & Hill, 1996) is a standardized self-report that uses a structured interview format to measure functional independence. There is an overall Global Independence score, as well as subscale measures of Motor Skills (e.g., “pours water into a glass from a pitcher or a bottle”), Social Interaction and Communication (e.g., “answers telephone call and writes down number for someone who is not there”), Personal Independence (e.g., “takes and reads own temperature when ill”), and Community Independence (e.g., “writes deposit and withdrawal slips for banking”). Scores are expressed as age-based standard scores ( $M = 100$ ,  $SD = 15$ ).

## RESULTS

The results are shown in Table 1. Math and numeracy scores were significantly lower than the population mean adjusted for education and/or age (Computation Accuracy  $t(30) = 2.5$ ,  $p = .020$ ; Computation Speed  $t(30) = 4.2$ ,  $p = .000$ ; Problem Solving  $t(30) = 2.4$ ,  $p = .021$ ; Functional Numeracy  $t(30) = 2.3$ ,  $p = .032$ ). Computation accuracy and computation speed did not differ, that is, the level of impairment in relation to age norms was similar for accuracy and speed measures. Within the group, each math measure was significantly poorer than Reading Decoding: Computation Accuracy,  $t(30) = 36.4$ ,  $p < .000$ ; Computation Speed,  $t(30) = 37.8$ ,  $p < .000$ ; Problem Solving,  $t(30) = 39.2$ ,  $p < .000$ ; further, Functional Numeracy was significantly lower than Functional Literacy,  $t(30) = 4.1$ ,  $p = .000$ .

Three of the four memory measures were significantly lower than the population mean of 10: Immediate Memory Capacity,  $t(30) = 3.1$ ,  $p = .004$ ; Immediate Memory Speed,  $t(30) = 5.5$ ,  $p < .000$ ; and Working Memory Capacity,  $t(30) = 4.2$ ,  $p = .000$ .

The role of numeric working memory was explored in a multiple regression conducted on the math computation accuracy scores, using two independent variables: highest immediate memory span and highest working memory span. Computation scores were selected because they were conducted in the same paradigm and with the same presentation and response modes as the working memory tasks; computation accuracy rather than speed was used because speed measures are normed on incorrect as well as correct responses. The overall regression model was significant,  $F(2, 30) = 5.5$ ,  $p = .009$ , and Computation Accuracy was related to Working Memory Capacity,  $t(30) = 3.3$ ,  $p = .003$ , but not to Immediate Memory Capacity.

TABLE 1  
Math and Cognitive Tasks

<i>Tasks</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>Range</i>
<b>Math</b>				
Computation accuracy <sup>a</sup>	31	8.3	3.9	1–13
Computation speed <sup>a</sup>	31	7.6	3.2	1–12
Problem solving <sup>a</sup>	31	8.9	2.4	4–13
Functional numeracy <sup>b</sup>	31	94.9	12.6	66–119
<b>Reading</b>				
Decoding <sup>b</sup>	31	106.5	14.7	77–132
Functional literacy <sup>b</sup>	31	102.9	12.8	76–131
<b>Memory</b>				
Immediate memory capacity <sup>a</sup>	31	8.2	3.2	3–15
Immediate memory speed <sup>a</sup>	31	7.1	2.9	1–13
Working memory capacity <sup>a</sup>	31	8.0	2.7	4–15
Working memory speed <sup>a</sup>	31	10.9	2.5	5–15
<b>Functional independence</b>				
Broad independence <sup>b</sup>	29	85.8	26.8	19–133
Motor independence <sup>b</sup>	26	58.9	34.9	0–131
Social-language independence <sup>b</sup>	29	101.3	17.3	51–129
Personal independence <sup>b</sup>	29	97.8	23.2	41–129
Community independence <sup>b</sup>	29	99.9	24.0	37–134

<sup>a</sup> $M = 10$ ,  $SD = 3$ . <sup>b</sup> $M = 100$ ,  $SD = 15$ .

An analysis of variance conducted on the adult math scores using childhood math status as the grouping variable showed that, longitudinally, individuals in the Math Impaired group as children showed poorer adult Problem Solving,  $F(1, 21) = 12.8$ ,  $p = .002$ , and Functional Numeracy,  $F(1, 21) = 5.9$ ,  $p = .024$ . They did not differ from the Math Unimpaired group on Computation Accuracy or Computation Speed. Childhood Problem Solving did not differ from adult Problem Solving or from adult Functional Numeracy on a Wilcoxon signed rank test, which shows that the rank order of individuals on these math tasks does not change from childhood to adulthood.

A greater number of lifetime shunt revisions was associated with poorer Functional Numeracy,  $F(1, 29) = 4.6$ ,  $p = .041$ , although the number of shunt revisions was unrelated to Computation Accuracy, Computation Speed, or Problem Solving. Spinal lesion level did not affect any math measure.

For the 29 individuals with ratings of Functional Independence, the Broad Independence measure differed from the population mean,  $t(28) = 2.9$ ,  $p = .008$ . Multiple regressions were conducted on individual Functional Independence subscales, using two independent variables: Functional Numeracy and Functional Literacy. The overall regression model for Social-Language Independence was significant,  $F(2, 28) = 9.9$ ,  $p = .001$ , adjusted  $R^2 = 0.4$ , with Functional Numeracy as the significant

regressor,  $t(28) = 3.4, p = .002$ . The overall regression model for Personal Living Independence was significant,  $F(2, 28) = 5.3, p = .012$ , adjusted  $R^2 = 0.2$ , with Functional Numeracy as the significant regressor,  $t(28) = 2.6, p = .015$ . The overall regression model for Community Independence was significant,  $F(2, 28) = 5.2, p = .012$ , adjusted  $R^2 = 0.2$ , with Functional Numeracy as the significant regressor,  $t(28) = 3.1, p = .004$ . The regression model for Motor Independence was not significant.

## DISCUSSION

Young adults with SBH show math computation and problem-solving skills that are poorer than age expectations and that are poorer than their own level of reading decoding. In parallel, their functional numeracy is compromised and is lower than their functional literacy. Longitudinally, poor math problem solving in childhood translates into poor problem solving and numeracy in adulthood. Together, the cross-sectional and longitudinal data support the hypotheses of developmental stability of math deficits in SBH.

Of those individuals with poor adult math, childhood instruction or remediation must have had limited success. Certainly, no systematic group intervention programs were instituted for the SBH participants, although many individual families had been energetic in attempting to obtain tutorial and academic remediation and had been diligent in providing home-based math instruction. An important question, not answerable from the present data, is how differences in childhood math instruction and remediation are associated with differences in adult math skill.

In childhood, one feature of written arithmetic skills in SBH is a slowed rate of development. Children with early hydrocephalus (including SBH) make a similar pattern of errors to younger, math accuracy-matched, children (Barnes et al., 2002). We did not measure written arithmetic in young SBH adults, so the longitudinal status of the slowed developmental rate is unclear. Children with SBH have difficulties in math domains other than computation (e.g., estimation, problem solving). It may be the case that, by young adulthood, they have found math to be frustrating and a source of little success, resulting in overall less experience than typically-developing young adults and earlier cessation of practice in integrating computation, procedures, and knowledge into effective math problem solving and functional numeracy. Certainly, the presence of a significant period of poor computations and difficulties in estimation and problem solving appears to translate into limited adult functional numeracy. In all, a slower rate of math development in childhood (perhaps accompanied by developmental deficits in math domains like geometry, estimation, and problem solving) may result in math deficits in young adulthood.

In adulthood, math problem solving is poorer than reading, and functional numeracy is poorer than functional literacy. Our comparison of reading and literacy involves mainly decoding and broad comprehension, but not inferential compre-

hension. It remains to be seen how higher-level comprehension develops in young adults with SBH. Young adults with SBH may be challenged by cognitive tasks requiring that relevant information be brought to a specific context to create a solution that goes beyond explicit information (e.g., making inferences, estimating, and problem solving), whether those tasks require reading or number skills.

Differences in computation skill appeared related to differences in numerical working memory. Computation accuracy was related to capacity and response speed for numerical working memory. That it was not related to the same measures for immediate number memory shows that the problem for math computation is neither the response mode of the memory task nor the generation of numbers, but rather the utilization of number information in working memory for math computation.

Earlier studies of working memory (Baddeley, 1986; Baddeley & Hitch, 1974) emphasized that slow oral articulation speed was associated with information decay and shorter working memory. More recent studies have shown, not only that articulation speed for nonwords does not differ in children with math disability and control children (Geary et al., 1999), but also that producing numbers from working memory involves two relatively uncorrelated processing rates: articulation time and interword pauses (Cowan et al., 1998), with mental processing occurring during the interword pauses.

Individuals with SBH have difficulty with both motor speech and lexical access. Their spontaneous speech shows specific features of ataxic dysarthria, namely, articulatory inaccuracy, prosodic excess, and phonatory-prosodic insufficiency (Huber, Dennis, Brettschneider, & Spiegel, 2001). On rapid naming tasks, children with SBH do not make naming errors, but do produce an excess number of scaffolds and fillers between words, which results in longer overall lexical access time (Dennis, Hendrick, Hoffman, & Humphreys, 1987).

Future studies with young SBH adults might explore numerical working memory in relation to ataxic dysarthria and slow lexical retrieval. In typically developing individuals, retrieval of names and numbers involves a memory search and reconstitution of partially decayed memory traces that occurs during interword pauses (Cowan et al., 1998). One hypothesis would be that working memory affects math computation in SBH adults because of slowed memory search and number reconstitution during the pauses between overt or covert number production.

The number of shunt revisions was related to functional numeracy, although not to formal arithmetic skills. In childhood, cognitive outcome is generally unrelated to number of shunt revisions (Guthkelch & Riley, 1969; Jensen, 1987; Raimondi & Soare, 1974; Tromp, Van Den Burg, Jansen, & De Vries, 1979; see, however, Halliwell et al., 1980); one reason being that frequent shunt revisions may imply prompt medical management to maintain a well-functioning shunt (McLone, Czyzewski, Raimondi, & Sommers, 1982; Wills, 1993). The present data show that some of the effects of lifetime shunt revisions may not be measurable until adulthood.

In SBH children, higher lesions restrict sensory growth and mobility (Soare & Raimondi, 1977), produce oculomotor problems (Tew & Laurence, 1978), provide fewer opportunities for perceptual-motor learning (Sand, Taylor, Hill, Kosky, & Rawlings, 1973; Simms, 1987), and are associated with poor visuospatial skills (Friedrich et al., 1991; Lonton, 1977; Tew, 1991; Wills et al., 1990). In the only study directly comparing SBH children and SBH adults, level of spinal lesion affected motor speech outcome in children more than in adults (Huber et al., 2001). Here, spinal lesion level was not associated with math outcomes.

Math processing involved a distributed neural system. Although the neuropathological substrate of poor math and numeracy in young SBH adults is not known, individuals with SBH have brain dysmorphology or hypoplasia in two regions, the posterior cortex and the cerebellum, that may be important for selected components of math processing.

Posterior brain regions, the parietal cortex particularly, have been implicated in arithmetic processing (Levin et al., 1996; Warrington, 1982; Whalen, McCloskey, Lesser, & Gordon, 1997), especially estimation and exact calculation with large numbers (Dehaene, Spelke, Pinel, Stanescu, & Tsiukin, 1999; Stanescu-Cosson, et al., 2000). Individuals with SBH have a characteristic anterior–posterior pattern of brain thinning, such that the parietal and occipital cortices are thinner than anterior cortical regions; this pattern is associated with poor nonverbal skills (Dennis et al., 1981; Fletcher et al., 1996). The integrity of the parietal cortex, which encodes numbers in a nonverbal quantity format (Stanescu-Cosson et al., 2000), may be important for math skills and numeracy in young SBH adults both directly, through an effect on components of math skills such as estimation, and indirectly, through an effect on supporting systems for working memory, by which information is kept in the focus of attention (Cowan, 1999).

Almost all cases of SBH are associated with the Arnold-Chiari II malformation, which involves herniation of the cerebellar tonsils through the exits of the fourth ventricle and which is correlated with reduction in cerebellar volume, especially in the neocerebellar hemispheres (Hetherington, Dennis, Kennedy, Barnes, & Drake, 1998). Cerebellar dysmorphologies are unlikely to affect math directly, although they could well prevent the learning and automatization of procedural knowledge (Thatch, 1997) and the imposition of temporal regularities on working memory (Hetherington, Dennis, & Spiegler, 2000), each of which could affect math function.

Whatever their neuropathological origin, problems in math and functional numeracy have significant implications for everyday function in young adults with SBH, just as they do for adults with various forms of brain injury (Deloche, Dellatolas, Vendrell, & Bergago, 1996). Functional independence was related to numeracy rather than literacy. Perhaps literacy measures concerned with iconic decoding rather than inferential comprehension do not challenge the higher levels of text comprehension. Perhaps, also, adult independence may require numeracy more urgently than literacy. Basic, iconic reading decoding is sufficient for many

everyday activities, but functional independence is restricted without the level of numeracy necessary to make change, shop for oneself, and hold a bank account. Math and numeracy problems in young adults with SBH, the endpoint of long-standing difficulties with a variety of math skills, are shown to limit functional independence, and are also likely to limit academic achievement and job opportunities.

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