A Matched Lesion Analysis of Childhood Versus Adult-Onset Brain Injury Due to Unilateral Stroke

Another Perspective on Neural Plasticity and Recovery of Social Functioning

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Background: The literature on neuroplasticity lacks a direct comparison of chronic neuropsychological and social outcomes following brain damage acquired in childhood versus adulthood, when lesions are matched across adults and children for size and location.

Methods: We paired adults and children with similar unilateral stroke lesions and then compared chronic neuropsychological and social outcomes. Quantitative comparisons were conducted, as well as qualitative analyses of each subject pair, focusing on specific domains of cognitive impairment and changes in social functioning.

Results: We found that learning and memory impairments were most common in both children and adults. Left hemisphere–lesioned children were normal on speech/language ratings, whereas their adult counterparts were borderline impaired. Impairments in social functioning were highly associated with hemispheric side of damage in adults, but not in children: Specifically, adults with right hemisphere lesions developed social defects much more frequently than adults with left hemisphere lesions, whereas this asymmetry was not evident in the children. Most importantly, though, was the overarching finding of a high degree of similarity between chronic neuropsychological and social function outcomes in adults and children with similarly located brain lesions due to unilateral stroke.

Conclusions: On balance, the findings suggest that lesion location and size are prepotent factors determining neuropsychological and social recovery from stroke.

Key Words: brain injury, unilateral stroke, neural plasticity, social functioning, pediatric stroke, adult stroke.

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There is longstanding scientific and clinical lore that pediatric stroke and adult stroke are different phenomena. For example, it is not uncommon to hear the adage that stroke onset in youth is "better" than in adulthood, in the sense that more recovery is likely with childhood onset. However, direct comparisons of the nature and severity of cognitive and social sequelae experienced by children versus adults following stroke have rarely been reported. In fact, no published studies, to our knowledge, have directly compared outcomes in adult-onset versus childhood-onset brain lesions due to stroke across a wide range of neuropsychological and social function measures. Furthermore, no studies have compared outcomes in young stroke patients who are carefully matched with adult stroke patients on lesion location and size. The current research begins to address this gap in our knowledge, through a direct comparison of long-term neuropsychological and social outcome data from pediatric and adult stroke patients whose lesions were carefully matched in terms of location and size.

The neuroplasticity debate is longstanding (for a detailed account of the historical background of the neuroplasticity literature, see Benton and Tranel).[1] One of the most noteworthy developments in neural plasticity research involved the work of Kennard,[2–4] which demonstrated that motor cortex lesions in infant monkeys produced less severe deficits than similar lesions in adult monkeys. This led to the development of the Kennard principle, which held that the earlier the brain damage occurred, the better the outcome would be. Other early researchers hypothesized that mechanisms of recovery included both regeneration of neural tissue and reorganization of the functioning of unaffected tissue.[5] Hubel and Wiesel[6] were also influential in the area, raising the notion of critical periods in neural development,[7] as demonstrated in experiments where deprivation of monocular input in infant kittens had an effect on development of striate cortex cells that was not demonstrated in adult kittens with similar sensory deprivation.

Compelling evidence for adult "plasticity" began to surface in the 1980s. Some general conclusions, offered by

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Kaas,[8] included the following: There appears to be reorganization of sensory maps after manipulation of sensory and other neural activity, with more active inputs expanding and less active inputs having less representation; the capacity for reorganization may be present at all levels of the nervous system, including subcortical and cortical; changes in sensory representations have been found to occur rapidly and slowly; and sensory reorganization at different levels of the nervous system has differential and sometimes cumulative effects. Neuropsychological studies of brain-damaged adults have demonstrated that in general, maximal recovery occurs in the first 3 months after the injury, and functional imaging studies have found that homologous areas in the unaffected hemisphere and areas neighboring the damaged tissue are active during tasks formerly mediated by damaged structures.[1] All of these developments in the plasticity literature have broadened the scope of the previous debate and emphasized the malleability of the nervous system, both of the immature organism and of the mature organism.

Children with strokes may experience substantial permanent impairments in cognitive abilities. With respect to linguistic development, Aram[9] reported that syntactical (grammatical) aspects of language were compromised in left hemisphere–lesioned children relative to normal comparison children and that this aspect of language never fully recovered. This pattern of impairment was not found in children with right hemisphere lesions, and syntax deficits were more evident in spoken syntax (as opposed to written). Studies by Bates and colleagues[10] and Aram[9] have pointed to the role of both the right and the left hemisphere in development of lexical learning, finding that childhood injury to either hemisphere resulted in a decrement in these abilities that also never fully recovered. Also, Pitchford[11] found that children who acquired left hemisphere lesions as a result of stroke before or during literacy acquisition (ages 2–6) had poor reading achievement, with reading age scores lagging behind chronologic age, despite resolution of acute aphasia syndromes. In these cases, delayed reading achievement was determined to be related to generally weak verbal processing abilities in participants with poor Verbal IQ scores relative to Performance IQ scores. However, in participants with no intellectual impairments (Verbal IQ in the normal range and consistent with Performance IQ), reading deficits were related to a specific deficit in phonologic processing (grapheme-to-phoneme translation).

Long-term outcome of executive functions was studied in children with ischemic strokes by DeSchryver et al.[12] These authors found that approximately 7 years after stroke, children with a variety of brain lesions had poorer problem-solving ability than normal control children, a majority of the children required remedial education, and one-third of the children's parents endorsed concerns about social and behavioral adjustment. These results were obtained despite the fact that most of the children recovered well from aphasia syndromes and had normal performances on tests of vocabulary knowledge. The authors concluded that some abilities are more detrimentally affected than others following brain injury. For instance, executive functioning (eg, problem-solving ability) may be more impacted, whereas language-related functions tend to recover more favorably. Anderson and colleagues have also studied developmental brain lesions and have found that the development of executive functions, personality, and social behavior is detrimentally affected by early-onset damage to ventromedial prefrontal regions.[13–15] Those studies, in fact, hinted at the interesting possibility that ventromedial prefrontal damage could actually be more devastating when incurred early in life than when incurred in adulthood.

In contrast to the aforementioned work, many studies examining neuropsychological outcomes of children following stroke have indicated that recovery is marked by impressive resiliency and improvement of neuropsychological functioning. For example, Aram and Ekelman[16] presented evidence that children with early left hemisphere lesions due to stroke showed no significant impairment in cognitive functions as measured by standardized intelligence tests, and right hemisphere–lesioned participants showed only minor degrees of impairment in IQ (scoring within the average range but lower than normal comparison children). With respect to academic skill achievement, Aram and Ekelman[16] found that most children with early unilateral cerebrovascular lesions, regardless of hemispheric side, acquired adequate reading and spelling skills. Although Ashcroft et al[18] concluded that left hemisphere lesions during childhood led to more pervasive deficits in mathematics than right hemisphere lesions (with children with earlier left hemisphere lesions lagging behind age-mates in declarative and procedural math knowledge), very few participants demonstrated the severity of arithmetic deficits typically seen following lateralized lesions occurring in adulthood (although this was not tested directly in this study).

Language production was directly compared in children and adults with unilateral brain injuries due to stroke.[19] This study compared adults and children on the same outcome measure, a language production task, but did not match the adults and children on any lesion variables other than hemisphere of involvement. The authors found that 5- to 8-year-old children with congenital lesions (acquired by 6 months of age) demonstrated almost no impairment in language production, regardless of lesion side, whereas adults showed the classic pattern of poorer expressive language abilities following left hemisphere injury. The authors also refer to two prior studies in which language comprehension was compared in adults and children with unilateral strokes; again, adult and child groups were not matched on any lesion variables aside from hemisphere of involvement. Both studies suggested that the children were not significantly impaired (both left hemisphere–damaged and right hemisphere–damaged children) compared with the adults, whose performances were significantly below age expectations.[20,21]

Some studies suggest that childhood-onset and adult-onset strokes may lead to similar degrees of neuropsychological impairment, but that the nature and patterns of neuropsychological impairment tend to differ. In a review article, Hogan et al[22] reported that studies examining intellectual test performance in pediatric stroke patients showed that children do not evidence the same pattern as adults of lower Verbal IQ following left hemisphere lesions and lower Performance IQ following right hemisphere lesions. Rather, children tended to show lower Performance IQ following stroke, regardless of lesion side, with relative preservation of Verbal IQ.[23,24] The presence of comorbid seizures significantly lowered Verbal and Performance IQ scores, regardless of lesion side.[24]

All together, previous work examining stroke outcome in children is decidedly mixed. The current study attempts to expand the neural plasticity literature by directly comparing outcomes in adult-onset versus childhood-onset unilateral stroke, with the addition of a crucial methodologic advance: In our study, children and adults were carefully matched on the critical variables of lesion location and size. This allows a more powerful test of the question of whether age at onset of brain damage (childhood versus adulthood) affects chronic outcomes across a wide range of neuropsychological and social function measures. To our knowledge, this is the first study to use a lesion-matching approach in the investigation of developmental brain lesions to further illuminate important issues such as neuropsychological and behavioral plasticity following brain damage. We should caution at the outset, though, that our study is preliminary and exploratory, and we did not have a strong a priori hypothesis. Based on the literature summarized above, it was possible that children could recover better than adults, or vice versa, or that children and adults would not differ, or that the nature and extent of recovery would depend on the domain of cognition or behavior under consideration. We sought to determine which of these possibilities turned out to be most correct in children and adult stroke cases that were carefully matched on lesion location and size.

METHODS

Participants

Thirteen child–adult pairs of left hemisphere–lesioned stroke patients and 16 child–adult pairs of right hemisphere–lesioned patients were included in this study. The mean age at stroke of the children was 3.2 (± 4.4) years, and the mean age at assessment was 12.4 (± 3.8) years. The mean age at stroke of the adults was 53.2 (± 16.0) years, and the mean age at assessment was 56.5 (± 15.0) years. Regarding age at assessment, then, the mean length of time since stroke onset for the children was 9.1 (± 4.6) years, and the mean length of time since stroke onset for the adults was 3.2 (± 3.5) years. Sixteen of the 29 children experienced prenatal, perinatal, or postnatal strokes occurring before the age of 6 months. Table 1 provides a detailed description of demographic information for the participants. Each child was matched with an adult, based on brain lesion location and size (details on the matching procedure are provided under Materials and Procedures). Table 2 enumerates lesion locations for the left and right hemisphere cases presented separately.

The adult stroke participants were recruited from a large registry of focal lesion patients in the Division of Cognitive Neuroscience at the University of Iowa Hospitals and Clinics, with the majority of participants hailing from the Midwest. The child stroke participants were also recruited from the University of Iowa Hospitals and Clinics. Importantly, both the adult and the child participants were drawn from the same basic demographic group, thus adding to the strength of our contention that the groups were generally well matched.

Materials and Procedures

Subject Selection and Lesion Matching

The general procedure for selecting participants was based on a two-part process: First, children were enrolled and their lesions charted; second, an adult match for each child was selected. The lesion-matching procedure was conducted blindly with respect to the neuropsychological outcome measures of interest. Children were enrolled first, as childhood lesions are much more rare and thus we were working from a much smaller database. The children were selected based on neuroimaging evidence of a single focal lesion due to stroke.[25] After the child lesions were identified, an adult counterpart was selected by searching the Patient Registry of the Division of Cognitive Neuroscience to find an adult with a matching lesion.

The lesion identification procedure was based on standardized neuroanatomical analysis[26] of brain computed tomography and/or magnetic resonance imaging films. A blind transfer of lesion contours was mapped onto a template

TABLE 1. Demographic Information on Left and Right Hemisphere Stroke Participants

	LH (n = 13)		RH (n = 16)	
	Children	Adults	Children	Adults
Age at onset (y)	3.0 (5.0)[2]	45.5 (14.8)[2,3]	3.4 (3.9)[1]	59.5 (14.6)[1,3]
Age at assessment (y)	12.8 (4.4)[5]	50.4 (13.3)[5,6]	12.1 (3.5)[4]	61.4 (14.9)[4,6]
Time since CVA (y)	9.8 (5.1)[9]	4.9 (4.4)[8,9]	8.6 (4.3)[7]	1.9 (1.9)[7,8]
Years of education	6.4 (4.0)[11]	12.5 (1.9)[11]	6.0 (3.5)[10]	12.0 (2.2)[10]
Handedness*	11/13 = LH	2/13 = LH	2/16 = LH	0/16 = LH

Values are means (SD). Superscripts indicate significant differences at $P < 0.05$, such that values that share the same superscript are significantly different from one another.

*The incidence of left-handedness was higher in the children, mainly in the left hemisphere group. However, based on family history information and clinical neuropsychological impressions (conducted independently of the assessments done in connection with the current study), we have no evidence that the children had "crossed dominance" for language. This has to be taken cautiously, though, because we do not have more definitive data (eg, Wada testing) for every participant.

LH, left hemisphere; RH, right hemisphere; CVA, cerebrovascular accident.

TABLE 2. Lesion Locations for Left and Right Hemisphere Stroke Pairs

Lesion Location	Left Hemisphere	Right Hemisphere
Frontal	1	1
Frontal–subcortical	2	1
Frontal–parietal	1	3
Temporal	2	
Parietal	1	1
Parietal–occipital		1
Temporal–parietal–occipital		1
Basal ganglia	3	4
Frontal–parietal–subcortical		1
Frontal–temporal–parietal–subcortical	3	1
Frontal–temporal–occipital–subcortical		1
Frontal–parietal–occipital–subcortical		1
Total	13	16

Values are nos. of pairs. Although approximately 55% of the children and the adults had encroachment of their lesion in the frontal lobe, only 9/29 (31%) of the children and 8/29 (28%) of the adults had the damage within the frontal lobe account for at least one-third of the extent of the lesion.

system, with 56 regions of interest coded for extent of involvement: 0 reflects no involvement of that region, 1 reflects <25% involvement of that region, 2 reflects 25–75% involvement, and 3 reflects >75% involvement of that region. The extent of the lesion from these two-dimensional data in adults and children involved adding the lesion score of each of the 56 regions of interest.

The templates of the children's lesions were used to visually match each child with an adult who had a similar stroke lesion based on location and size. This matching procedure was blind to any of the outcome data of interest, as it was made based entirely on the lesion data and irrespective of any neuropsychological or social function data. The precedent for this type of matching procedure is derived from that used by Anderson et al,[27] in which tumor and stroke lesions were matched based on size and location. After the initial visual matching procedure, the quality of the matches was validated in two ways. First, a subset of the matches were subjected to a critical review by a member of our laboratory who is a lesion analysis expert to verify which matches were sufficient for this type of study. Second, the lesion codes for each pair were compared to determine the extent of similarity between the lesions (eg, which brain regions were coded as being involved and the extent of involvement of those regions). If any matches were identified as suboptimal, a more appropriate adult counterpart was selected from the Patient Registry.

Our approach to further validate the lesion matching between children and adults consisted of two additional phases. First, in the children, we compared the two-dimensional measure of the extent of the lesion (n = 29) with the three-dimensional extent of the lesion (n = 26) (see below). This step was conducted to validate the two-dimensional method that was used for both the children and the adults with lesions. Second, we compared the two-dimensional measure of the extent of the lesion in the children with the corresponding measure in the adults.

Step 1: Almost all the children (n = 26) had three-dimensional volumetric analyses conducted. Guided by lesion markings, an experienced neuroanatomist "painted" each lesion using a three-dimensional brain morphometrics package (Display; Montreal Neurologic Institute, Montreal, Quebec, Canada). Lesion volume was computed in absolute units (cm^3) before and after normalization for intersubject differences in brain size.[28] Size normalization was performed using spatial normalization software, which has the user mark the front, back, left, right, top, and bottom of the brain following anterior–posterior commissure alignment. Spatial normalization then sized the brain along each axis to the template size, thus correcting for brain size. The bivariate correlation of the three-dimensional extent of the lesion (cm^3) and the two-dimensional measure of the extent of the lesion was 0.901 ($P < 0.000$). This suggests that the derived measure of the two-dimensional extent of the lesion correlates very highly with the precise volumetric measurement.

Step 2: With the support of the validation of the two-dimensional measure of the extent of the lesion, this measure was compared in the children (n = 29) and their matched adults (n = 29). The bivariate correlation was 0.694 ($P < 0.000$). Thus, we concluded that the extents of the lesions in the children and adults were moderately to highly correlated. However, moderate to high correlations do not prove that the lesion extent is similar between the children and the adults. Therefore, we directly compared the lesion of each child with his/her adult match. The children's lesions were larger than their adult matches in 16 of 29 cases, and there were 2 ties. The distribution of lesion size was not normal, so a Wilcoxon Signed Ranks Nonparametric Test of related samples was conducted. The result was not significant. This indicated that the lesions were not significantly different in size between the child and adult groups.

Neuropsychological Assessment

Participants were assessed with standardized neuropsychological tests. Intelligence was assessed using the Wechsler Adult Intelligence Scale, 3rd ed. (WAIS-III),[29] and the Wechsler Intelligence Scale for Children, 3rd ed. (WISC-III).[30] Academic achievement was assessed using the Wide Range Achievement Test–Revised (WRAT-R).[31] Speech and language abilities were assessed using subtests from the Multilingual Aphasia Examination,[32] including the Token Test, Controlled Oral Word Association Test, and Sentence Repetition Test. Anterograde verbal memory was assessed using the Rey Auditory Verbal Learning Test[33] (AVLT) for the adults and the California Verbal Learning Test–Children's Version[32] (CVLT-C) for the children. Visual construction and anterograde visual memory were assessed using the Rey–Osterreith Complex Figure Test, Copy and Delayed Recall.[35] Executive functions were assessed using the Wisconsin Card Sorting Test.[38] (It should be noted that the children and adult participants in most cases received considerably more extensive neuropsychological assessments than what is reported here. Given the goals of the current study, we focused on only those measures for which data were available for most of the children and adult participants, and appropriate normative data for both children and adults were available. These restrictions forced us to omit some neuropsychological measures, but this sacrifice was considered meritorious because it allowed a more definitive comparison of the children and adult participants.)

Neuropsychological assessments were conducted in the chronic epoch for each participant (approximate mean of 9 years since onset for the children and approximate mean of 3 years since onset for the adults). Raw scores on each neuropsychological test were converted to age-corrected standard scores according to available normative information, either as *z* scores, percentiles, or scaled scores. Spontaneous speech was also rated subjectively for each participant based on the following classification: 1 = no impairment, 2 = mild or borderline impairment, and 3 = clearly impaired. Aspects of speech and language including word finding, fluency, prosody, articulation, use of paraphasias, and oral comprehension were rated. For the children, the speech ratings were obtained via evaluation of videotapes of a narrative discourse task in which participants were asked to make up a story based on a series of pictures. The adults' speech and language ratings were made contemporaneously based on spontaneous speech and responses during clinical interviews.

Social Functioning

We also measured the domain of Social Functioning contemporaneously with the neuropsychological assessment. In the adults, we used the following procedures, modeled on some of our previous work.[36] Structured clinician-based rating scales were used to assess the overall social conduct of each patient and to rate the patient's Social Functioning and Interpersonal Relationships. Family ratings of the patient's social conduct were also obtained. The Employment Status of each patient was determined at the time of our evaluation. Clinician Ratings were performed by clinical neuropsychologists who were naive as to the objectives of the current study. In the children, the domain of Social Functioning was measured in a parallel fashion. A necessary modification was the substitution of a children's measure corresponding to the Employment Status of the adults, namely, involvement in Special Education.[37] The Clinician Ratings were performed blind to the scores of the individually matched adult stroke subjects.

The extent of change or impairment in various aspects of social conduct was rated on a 3-point scale (1 = no change or impairment, 2 = moderate change or impairment, 3 = severe change or impairment). A postlesion change or impairment in Employment Status was defined as an alteration in the patient's procurement or level of occupation (eg, inability to sustain gainful employment). The corresponding childhood measure was a postlesion change or impairment in Educational Status, which was defined as an alteration in the patient's educational placement or involvement and/or needs for special education. The relevant subscale on the Glasgow Outcome Scale–Expanded, Child's Version,[37] was used. A postlesion change or impairment in Interpersonal Functioning was defined as an alteration in the patient's ability to maintain normal social relationships with significant others such as friends and family. Clinician Rating of change or impairment was based on multiple sources of evidence, including interview data, neuropsychological performance, and information gathered from collaterals.

RESULTS

Neuropsychological Functioning

Two types of analyses, quantitative and qualitative, were carried out. Several types of quantitative analyses were conducted, including analysis of variance, paired *t* tests, and effect size calculations.

Quantitative Analyses

Analyses of variance (ANOVAs) were conducted (2×2 ANOVAs) using subject type (child versus adult) and lesion side (left versus right) as independent factors. No interaction effects were found, and there were almost no significant main effects, with two exceptions. Relative to age expectations, children performed worse than adults on the Rey–Osterreith Complex Figure Copy and on the Rey–Osterreith Complex Figure Recall (combining both the left and right hemisphere cases). For the Complex Figure Copy, the mean children's *z* score was −2.1 (SD = 3.4) compared with the adults' mean *z* score of −0.5 (SD = 1.8; $P < 0.025$). For the Complex Figure Recall, the mean children's *z* score was −1.5 (SD = 1.2), whereas the adult's mean *z* score was −0.6 (SD = 1.3; $P < 0.012$).

Paired quantitative analyses were also conducted, such that each child–adult pair was compared in a within-subjects or paired *t*-test design. This was accomplished for the left and right hemisphere cases separately. Within the right hemisphere cases, there were almost no significant paired *t* tests with the exception of poorer performance on a test of auditory verbal memory in the children (CVLT-C Delayed Recall *z* score of −0.6, SD = 1.1) versus in the adult pairs (Rey AVLT Delayed Recall *z* score of 0.6, SD = 1.8; $P < 0.029$). Within the left hemisphere cases, there were few significant paired *t* tests. Children performed significantly worse than their adult pairs on a test of visual construction (Rey–Osterreith Copy *z* score for children = −2.4, SD = 3.1, versus adults' *z* score = −0.1, SD = 1.6; $P < 0.034$). Children with left hemisphere lesions also performed significantly better than their adult counterparts on paired-subject comparisons of several speech and language ratings, including word finding, fluency, oral comprehension, and paraphasic errors (Table 3). These comparisons were conducted using Wilcoxon Signed Ranks

TABLE 3. Wilcoxon Signed Ranks Tests (Paired Nonparametric Tests) Comparing Children Versus Adults with Left Hemisphere Strokes on Speech and Language Ratings

	Child	Adult	Significance Level
Word finding	1.0 (0.0)	2.0 (1.0)	0.011
Fluency	1.0 (0.0)	1.8 (1.0)	0.025
Paraphasic errors	1.0 (0.0)	1.8 (1.0)	0.025
Comprehension	1.0 (0.0)	1.6 (0.8)	0.038

Values are means (SD). 1 = normal; 2 = borderline impaired; 3 = clearly impaired.

Tests (a paired nonparametric test), as the scores on some speech and language ratings for the children were not normally distributed.

Effect size calculations were also carried out for left hemisphere and right hemisphere participants separately, such that children were contrasted with adults to determine if there were significant effects of subject type (children versus adults) on each of the neuropsychological measures. The effect sizes were computed using the standard formula of taking the mean of group 1 minus the mean of group 2 and then dividing this number by the pooled standard deviation. Then an unbiased estimate of effect size was calculated using a correction factor.[39] Confidence intervals were computed at the 95% confidence level to quantify the margin of error around the effect size estimate.

In general, almost all effect sizes were very small. For the right hemisphere subjects, the only notable effect was for the Recall condition of the AVLT (Rey AVLT or CVLT-C). The adults (Recall z score = 0.55, SD = 0.81) performed better than the children (Recall z score = −0.59, SD = 1.05). The effect size was 1.17 (considered a "large" effect), with a 95% confidence interval of 0.36–1.97. For the left hemisphere participants, very few effect sizes were of consequence. The Copy condition of the Rey–Osterreith Complex Figure was performed more accurately by the adults (Copy z score = −0.059, SD = 1.56) than by the children (Copy z score = −2.38, SD = 3.13). The effect size of 0.91 (a "large" effect) had a 95% confidence interval from 0.10 to 1.72. Four of the five larger effects involved speech and language ratings, in the domains of word finding, fluency, paraphasic errors, and auditory comprehension, and in all cases, the adults performed worse than the children (in the more pathologic direction on the scale where 1 = no impairment, 2 = borderline impairment, and 3 = clearly impaired). The mean scores, unbiased effect sizes, and 95% confidence intervals are detailed in Table 4, along with the other significant effects. (No statistically nonsignificant effects were included in Table 4.)

Qualitative Analyses

A qualitative pair-by-pair profile analysis was conducted for each of the stroke pairs, separately for the left hemisphere–lesioned subjects and the right hemisphere–lesioned subjects. The neuropsychological outcome measures were categorized into eight broad domains of cognitive functions, including intellectual functions, attention/concentration, academic skills, expressive language, receptive language, visual–motor abilities, learning/memory, and executive functions. A box-score method was used to make "impaired" versus "not impaired" judgments for each subject under each domain of cognitive functioning. The general criterion used to define "impairment" was a score ≥2 SDs below the age-expected mean (This entire series of analyses was repeated, using a 1.5-SD criterion for "impairment" instead of a 2.0-SD criterion. The pattern of results was essentially identical to that reported for the 2.0 criterion analyses; in particular, there were few notable between-group differences regarding the adult versus child pairs. We also conducted the analyses using a 1.0-SD criterion; again, the general pattern of results was relatively similar [although more differences emerged in the 1.0 analyses, as would be expected based on the liberal threshold of this criterion]. We have opted to report detailed results only for the 2.0 criterion analyses, as this is the most clinically meaningful criterion for defining "impairment"), thus taking normative developmental expectations into account so as not to unfairly compare children and adults on raw scores without age correction. This 2-SD cut-off was equivalent to an IQ score of ≤70, a standard score of ≤4, a z score of −2.0 or less, or a percentile of ≤2.

In the category of intellect, a judgment of "impaired" was made if either Full-Scale IQ, Verbal IQ, or Performance IQ fell at or below 70. In the category of attention/concentration, subjects were rated as "impaired" if their age-corrected scaled score on the Digit Span subtest of the WAIS-III, WAIS-R, or WISC-III fell at or below 4. In the category of academic skills, subjects were rated as "impaired" if their scores on the WRAT-R Reading or Arithmetic subtests fell at or below 70 or if the scores were 2 SD (30 points) below their Full-Scale IQ (commensurate with standard definitions of a learning disability). In the expressive language domain, subjects were judged as "impaired" if their scores on any expressive language test (Controlled Oral Word Association Test, Sentence Repetition Test) fell at or below the 2-SD cut-off or if the speech and language ratings on any expressive dimension (word finding, fluency, paraphasic errors, articulation, prosody) were rated as a 3 (indicative of being "clearly impaired"). In the receptive language domain, subjects were judged as "impaired" if their score on the Token Test fell at or below the 2-SD cut-off or if the speech and language rating on

TABLE 4. Large Effect Sizes and 95% Confidence Intervals for Comparison of Children Versus Adults (Left and Right Hemisphere Cases Separately)

Outcome Measure	Mean (SD) of Adults	Mean (SD) of Children	Effect Size (Unbiased Estimate)	Lower 95% Confidence Interval	Upper 95% Confidence Interval
RH: Rey AVLT, CVLT-C Recall	z = 0.55 (0.81)	z = −0.59 (1.05)	1.17	0.36	1.97
LH: word-Finding rating	2.00 (1.00)	1.00 (0.0)	1.37	0.52	2.22
LH: fluency rating	1.77 (1.01)	1.00 (0.0)	1.04	0.22	1.86
LH: rating on paraphasia use	1.77 (1.01)	1.00 (0.0)	1.04	0.22	1.86
LH: rating on comprehension	1.54 (0.78)	1.00 (0.0)	0.95	0.14	1.76
LH: Rey–Osterrieth Copy	z = −0.059 (1.56)	z = −2.382 (3.13)	0.91	0.10	1.72

In cases where SD = 0, an estimate of 0.0001 was used to be able to compute the effect size.
RH, right hemisphere; AVLT, Auditory Verbal Learning Test; CVLT-C, California Verbal Learning Test–Children's Version; LH, left hemisphere.

the dimension of oral comprehension was rated as a 3 (indicative of "clearly impaired"). The visual–motor domain was judged based on scores on the Rey–Osterreith Complex Figure Copy condition (*z* score). The learning and memory domain was judged as "impaired" based on trial 1, trial 5, or delayed recall trial scores on AVLTs (Rey AVLT or CVLT-C) or if the Delayed Recall of the Rey–Osterreith Complex Figure Test was at or below the 2-SD cut-off. A judgment of "impaired" was made in the domain of executive functions if any of the three recorded measures on the WCST met the 2-SD cut-off (categories completed, perseverative errors, or total errors). Results for the left hemisphere–damaged pairs are depicted in Table 5, and results for the right hemisphere–damaged pairs are depicted in Table 6. There was no obvious relationship of number of impaired domains of functioning of children versus adults based on which member of the pair had a larger lesion.

Some general conclusions can be derived from inspecting the results of qualitative profile analyses. First, learning and memory impairments were most common among all subjects (both children and adults, left hemisphere and right hemisphere lesions). Second, impairments in academic skills were more common among the children than the adults. Third, receptive and expressive language impairments were more common in adults with left hemisphere lesions than in children with left hemisphere lesions. Fourth, visual–motor (visual–construction) impairments were more common in children with left hemisphere lesions than in adults with left hemisphere lesions. Notably, however, all children with these impairments were left handed. This raises the strong possibility that those children transitioned to being left handed after experiencing right hemiparesis, and poor performance on visual–construction tasks may thus reflect clumsiness in the use of the left hand. Fifth, attention impairments were more common in left hemisphere–lesioned adults than in left hemisphere–lesioned children, but in all these cases, the adults also had impairments in expressive language. The attention measure that was used, the Digit Span subtest of the Wechsler scales, requires oral expression of numbers and is confounded with expressive language ability. Last, and perhaps most importantly, there did not appear to be a consistent pattern of adults performing worse than children or vice-versa. There were nearly equal numbers of subject pairs in which the child member of the pair was impaired in more domains than the adult, the adult was impaired in more domains than the child, or the number of impaired domains was equal across both members of the pair. For example, among the left hemisphere

TABLE 5. Qualitative Pair-by-Pair Analysis of Left Hemisphere Cases

LH Cases	Intelligence	Attention	Academic Skills	Experimental Language	Receptive Language	Visual Motor	Learning/Memory	Executive Function
Child 1*							C	
Adult 1	A	A	—	A	A	A	A	—
Child 2*								
Adult 2*							A	—
Child 3*								
Adult 3			—				A	—
Child 4*				C				
Adult 4		A		A	A			—
Child 5		—						
Adult 5								—
Child 6*						C	C	
Adult 6			—					
Child 7*	C	C	C				C	
Adult 7		A	—	A	A			A
Child 8*		—	C	C	C		C	—
Adult 8			—					
Child 9*						C	C	
Adult 9*				A				—
Child 10								
Adult 10	A	A	A	A	A			—
Child 11*			C	C		C	C	C
Adult 11		A	—	A				—
Child 12*	C	C	C			C	C	C
Adult 12			—					—
Child 13*	C	C	C	C		C	C	
Adult 13		A		A	A			

A denotes impairment for the adult subject; C denotes impairment for the child subject; — denotes missing data. Impairment is defined as a score ≥2 SDs below the age-adjusted mean.

*Left-handed subject.

LH, left hemisphere.

TABLE 6. Qualitative Pair-by-Pair Analysis of Right Hemisphere Cases

RH Cases	Intelligence	Attention	Academic Skills	Experimental Language	Receptive Language	Visual Motor	Learning/Memory	Executive Function
Child 1	C	C	C	C		C	C	
Adult 1			—			A	A	
Child 2		—						
Adult 2							A	
Child 3		—	C	C		C	C	
Adult 3							A	—
Child 4	C							
Adult 4			—					—
Child 5							C	C
Adult 5	A					A		—
Child 6						C	C	
Adult 6								
Child 7			C	C			C	A
Adult 7				A		A		
Child 8*			C	C	C		C	—
Adult 8				A				
Child 9							C	—
Adult 9				A		A		
Child 10		—					C	
Adult 10				A	A			—
Child 11								
Adult 11								
Child 12								—
Adult 12			—					
Child 13	C		C	C		C	C	
Adult 13			—	A				
Child 14*								
Adult 14								
Child 15								
Adult 15			—				A	—
Child 16		—	C					
Adult 16	A		—	A		A		

A denotes impairment for the adult subject; C denotes impairment for the child subject; — denotes missing data. Impairment is defined as a score ≥2 SDs below the age-adjusted mean.

*Left-handed subject.

RH, right hemisphere.

pairs, there were five pairs in which the adult demonstrated more impairment, six pairs in which the child demonstrated more impairment, and two pairs in which the number of impaired domains was equal across both members of the pair. Among the right hemisphere pairs, there were four pairs in which the adult was impaired in more domains, six pairs in which the child was the impaired in more domains, and six pairs in which the number of impaired domains was equal across both members of the pair. Thus, the overall level of impairment judging by pair-by-pair qualitative profile analysis was not impressively different, but the pattern was somewhat different in terms of which domains of cognitive abilities were affected for children versus adults.

Social Functioning

Turning now to the domain of Social Functioning, we examined the adult and child participants with the following analyses. We assessed differences among adult subjects and among child subjects with Kruskal–Wallis Nonparametric Tests. We assessed differences between matched pairs of adults and children with Wilcoxon Signed Rank Nonparametric Tests. The results are reported in Table 7.

In the adult participants, the development of impairments in various aspects of Social Functioning following stroke was strikingly different between left hemisphere– and right hemisphere–damaged subjects. Changes in the domains of Interpersonal Functioning and Clinician Rating were almost nonexistent in the left hemisphere–lesioned adults. By contrast, moderate to severe changes in all measured aspects of Social Functioning were nearly ubiquitous in the right hemisphere–lesioned adults. These differences between right and left hemisphere–lesioned subjects were statistically significant: Interpersonal Functioning (Kruskal–Wallis test $\chi^2 = 15.08$, $df = 1$, $P < 0.0005$), Clinician Rating (Kruskal–Wallis Test $\chi^2 = 9.27$, $df = 1$, $P = 0.002$). In the left hemisphere subjects, the only domain that changed in an appreciable

TABLE 7. Social Function: Comparing Children Versus Adults with Left and Right Hemisphere Strokes Using Wilcoxon Signed Ranks Tests (Paired Nonparametric Tests)

	Child	Adult	Significance Level
Left hemisphere			
Employment status/Special education status	1.54 (0.66)	1.69 (0.75)	NS
Interpersonal functioning	1.69 (0.75)	1.00 (0.00)	0.014
Clinician rating	1.85 (0.69)	1.15 (0.38)	0.013
Right hemisphere			
Employment status/Special education status	1.56 (0.63)	2.38 (0.72)	0.004
Interpersonal functioning	1.63 (0.72)	2.25 (0.86)	0.061
Clinician rating	1.63 (0.62)	2.13 (0.89)	0.046

Values are means (SD). 1 = no change/impairment; 2 = moderate change/impairment; 3 = severe change/impairment.
There are 13 left hemisphere lesion pairs and 16 right hemisphere lesion pairs.

number of subjects (7/13) was Employment Status, likely secondary to disability from acquired cognitive deficits (eg, aphasia). Nevertheless, subjects with right hemisphere lesions were significantly more impaired regarding Employment Status than their counterparts with left hemisphere lesions (Kruskal–Wallis test $\chi^2 = 5.22$, $df = 1$, $P < 0.03$).

The child participants with left versus right hemisphere lesions were not significantly different in any of the Social Functioning outcome variables, that is, Special Education Status, Interpersonal Functioning, and Clinician Rating (all $P > 0.38$).

Of greatest interest for the purposes of the current study is the comparison of adult and child participants, matched for lesion location and size. The Wilcoxon Signed Rank Test was used for these analyses. Social Function outcome was compared between the adult group (n = 29) and the child group (n = 29). The groups were not significantly different regarding Interpersonal Function or Clinician Rating. However, the adults had significantly greater impairment with regard to Employment Status compared with the children's corresponding Special Education Status ($Z = -2.86$, $P = 0.004$). The separate analyses comparing matched pairs of adults/children with left hemisphere lesions and then with right hemisphere lesions were more informative (see Table 7).

Left Hemisphere Lesion Social Function Outcome Analyses

There was no significant difference between the Employment Status of adults and the corresponding Special Education Status measure in children. However, children were more impaired than their adult left hemisphere matches with respect to Interpersonal Functioning ($Z = -2.46$, $P = 0.014$) and Clinician Rating ($Z = -2.50$, $P = 0.013$).

Right Hemisphere Lesion Social Function Outcome Analyses

Adults were significantly more impaired than their child right hemisphere matches with respect to Employment Status/Special Education Status ($Z = -2.92$, $P = 0.004$) and the Clinician Rating ($Z = -1.99$, $P = 0.046$). Adults tended to be more impaired than the children regarding Interpersonal Functioning ($Z = -1.87$, $P = 0.061$).

DISCUSSION

The most striking and perhaps most surprising conclusion from our study is the degree of similarity between chronic neuropsychological and social outcomes in children and adults with similarly located brain lesions due to unilateral stroke. Given the number of analyses that were conducted on the many different outcome measures, it is impressive that very few differences were found when comparing children versus adults as a whole, left hemisphere–lesioned children versus left hemisphere–lesioned adults, and right hemisphere–lesioned children versus right hemisphere–lesioned adults. The degree of similarity in chronic outcomes (ie, outcomes occurring on average 3 years after stroke for adults and 9 years after stroke for children) is, on balance, striking.

Despite this similarity, the quantitative statistical analyses suggest a few fairly consistent findings worth mentioning. First, children with left hemisphere lesions appeared to demonstrate difficulty with tasks requiring visual–motor integration (ie, visual construction or drawing of a complex figure). Initially, this finding might seem counterintuitive as one might expect that children with right hemisphere lesions would be more susceptible to problems with visual construction rather than children with left hemisphere lesions. This finding makes more sense when examined in the context of the fact that many of these children were left handed, suggesting that their poor scores on visual–motor tasks could reflect inefficiency in learning to use the left hand, a change in handedness that was probably initiated by right hemiparesis following left hemisphere damage.

Second, speech and language ratings appeared to be normal in children with chronic left hemisphere lesions but mildly abnormal in adults with chronic left hemisphere lesions. These differences were most apparent on measures of observed difficulty with word finding, fluency, presence of paraphasic errors, and comprehension of spoken information. In fact, no children were rated as abnormal on any of these dimensions, using the same criteria that were used to judge the speech and language abilities of the adults in this sample. This finding is consistent with research reviewed in the introductory text, demonstrating that damage to language-related neural structures in children inflicts less permanent speech and language impairment than similar damage in adults. However, support was garnered only on qualitative ratings of speech and language abilities and not on formal tests such as subtests from the Multilingual Aphasia Examination. In fact, average scores on the Token Test, Controlled Oral Word Association Test, and Sentence Repetition Test were not significantly better for the children with left hemisphere lesions than for adults with matched lesions. At issue here may be the sensitivity of the formal tests and even the qualitative speech/language assessments. For example, a more sensitive measure of narrative discourse in a subset of this child cohort elicited impairment especially in children with lesion acquisition before age 1.[40]

A third finding was that anterograde verbal memory scores were stronger for adults with right hemisphere lesions than for children with similar lesions. The same effect was not seen in left hemisphere–lesioned subjects. Overall, though, the mean score for right hemisphere–lesioned children was still within the average range and within 1 SD of the mean. This suggests that although adults performed slightly stronger than children with similar lesions in this domain, the children were not actually "impaired" in verbal memory. The explanation behind stronger performance in the right hemisphere adults compared with the right hemisphere children is unclear, and this finding warrants further investigation. One intriguing possibility is the so-called "crowding hypothesis," which posits that early brain lesions lead to more cognitive functions being represented in the contralesional hemisphere, leading to a "crowding out" of some abilities. The nonlesioned hemisphere (in this case, the left hemisphere) carries the burden of serving the usual functions associated with that hemisphere (eg, verbal processing and verbal memory) but also acquires responsibility for subserving some cognitive functions of the injured hemisphere (eg, nonverbal memory), and thus some abilities end up compromised owing to this overburdening. A possibility is that in children with right hemisphere lesions, the burden of visual memory came to be subserved by the functioning left hemisphere and led to a decrease in the function usually served by the left mesiotemporal area, namely, verbal memory. This hypothesis warrants further investigation.

Fourth, the pattern of social function outcome was intriguing. In adults, there was a clear and potent effect of hemispheric side of damage. Adults with right hemisphere lesions fared significantly worse than adults with left hemisphere lesions in all domains of Social Function measured (Employment Status, Interpersonal Status, and Clinician Rating). This is consistent with previous studies and may be related, in part, to deficits in empathy and disruption in everyday decision making and emotional processing[14,41,42] often associated with right-sided lesions. In contrast, the children with left versus right hemisphere lesions were not significantly different with respect to social function outcome. Both groups of children exhibited mild to moderate impairments, on average. This finding of the apparent absence of an effect of lesion laterality is consistent with the finding of a relative lack of laterality findings as well as the presence of mild to moderate impairment regarding neuropsychological functions in this cohort[43] and others.[23,24,44,45]

This led to the interesting finding that children with right hemisphere lesions had significantly better social outcomes than adults with matched lesions. A finding of this nature suggests a process of plasticity buffering the children from more severe social outcome impairment. Further evidence of plasticity favoring children were analyses comparing the entire child cohort with the entire adult cohort, which found that outcome was significantly worse for adults regarding Employment Status/Special Education Status. However, if this is a function of plasticity, it is clear that the process of plasticity is domain selective. Children do not simply have better social outcomes than their lesion-matched adults. First, the child cohort and the adult cohort as a whole did not differ significantly in social outcomes other than Employment Status/Special Education Status. Second, children with left hemisphere lesions were significantly more impaired in their social function outcomes than adults with matched lesions. The latter finding may imply that plasticity processes involved recruitment of other brain areas—possibly in the right hemisphere—to subserve critical left hemisphere functions such as language and thereby compromised areas which are generally destined (in the absence of brain damage) to subserve a variety of social functions. This would be consistent with our finding that children with left hemisphere lesions had significantly better language function but significantly worse social outcomes than adults with matched lesions.

Results from the qualitative pair-by-pair profile analysis also lead to some general conclusions. First, academic skill impairments were more likely to be seen in children than their adult counterparts. This finding is consistent with those of Pitchford[11] that suggest that lesions acquired in childhood before literacy acquisition detrimentally affected the development of reading skills, both in children who suffered general declines in verbal processing (Verbal IQ relative to Performance IQ) and in children who merely showed a deficit in basic phonics skills without poor Verbal IQ. Together these results suggest the possibility that children with unilateral strokes who have not yet fully developed academic skills might be more prone to problems in this area than adults with unilateral strokes in whom these skills were already firmly established. However, it is important to note that even though there seems to be greater vulnerability to poor academic skill development in children with strokes as compared with adults with similar strokes, the majority of children in both the left hemisphere and the right hemisphere groups did not show impairment in this area. Additionally, in several cases in which the child member of the pair demonstrated an academic skill impairment, the adult was not administered the relevant academic skill test, and thus we have missing data that further dilutes the salience of this difference.

Another conclusion from the pair-by-pair profile analysis is that learning and memory impairments appeared to be the most commonly demonstrated weaknesses, for both children and their adult counterparts with both the left hemisphere–lesioned group and the right hemisphere–lesioned group. This finding was not necessarily anticipated based on the extant literature but is not all that surprising, given the prevalence of learning and memory impairments encountered in clinical practice with stroke patients. Several cognitive abilities are paramount in successful performance on a learning and memory task, including attention to the task at hand, organization of the to-be-learned information, adequate rehearsal and encoding, consolidation, and retrieval. Damage to brain structures affecting any of these abilities could impair or at least hinder performance on the final outcome measure: delayed spontaneous recall of an orally presented word list. Therefore, it is possible that the frequency of learning and memory impairments demonstrated by our sample is expected, given that this type of task is very sensitive to any type of brain dysfunction in general, as there are so many prerequisite cognitive abilities required for successful performance. Likewise, the finding from qualitative analyses that more left hemisphere–lesioned adults showed attention impairments than left hemisphere–lesioned children also could be due to the fact that several abilities are paramount to successful completion of the particular attention measure that was used, the Digit Span subtest from the Wechsler scales. This is strengthened by the fact that all adults with impairments in this domain also had impairments in expressive language.

Additional conclusions from the qualitative profile analyses echo those garnered from the quantitative analyses: Some aspects of speech and language abilities were more fully recovered in children with left hemisphere lesions than in their adult counterparts with similar lesions, and second, more children with left hemisphere lesions experienced visual–motor impairments than adults with similar lesions.

Last, the overall degree of impairment, as reflected in the number of impaired cognitive domains, was not consistently greater for children or adults. There appeared to be almost equal numbers of pairs in which the adult seemed more impaired than the child with a similar lesion and vice versa, or both members of the pair were impaired along the same number of cognitive domains. These findings echo the larger conclusion from this study that was somewhat surprising, given the literature on neural plasticity. That is to say, we did not find compelling evidence of striking differences between the degree and patterns of recovery in chronic neuropsychological functioning in children and adults with very similar brain lesions.

The fact that our subjects were matched based on brain lesion location and size is a novel approach to studying this question and helps refute the argument that the reason the children were not found to be more fully recovered was because of some systematic bias in the amount and nature of neuroanatomical damage between the children and the adults who were studied. Our lesion-matching approach to this issue is certainly one of the main strengths of this study, and we hope other authors will attempt to replicate and extend our findings using this scientifically rigorous approach. Another strength of our study is the fact that we examined chronic outcome data, and these findings have some clinical relevance for what practitioners are able to tell their patients to expect "in the long run." Pediatric neuropsychologists probably get this question from parents of their patients more often than any other question (ie, "What will my child be like in 5–10 years, and will this problem ever recover?"). This type of chronic outcome data is often lacking in stroke research, and child samples are especially challenging to follow over long intervals for obvious reasons.

Some weaknesses in this study that we would have liked to have addressed include that we had more missing data for the adults, particularly on tests of academic skills and executive abilities, than we did for the children. Given the fact that we were using retrospective data, we had little remedy for this problem. Certainly, a longitudinal design might be a more effective approach to dealing with this issue in future research. Additionally, we had only one measure of attention and concentration, the Digit Span subtest of the Wechsler scales, which is potentially confounded with language abilities. Ideally, we would have used other measures as well (such as Trail Making Test A) without the same language requirements. Other such measures were not used consistently enough in testing our subjects to make meaningful comparisons between and within groups. Last, although we attempted to match brain lesions as closely as possible and used two clinical anatomic methods to optimize the quality of the matches (expert judgments and lesion code cross-checking), complemented by statistical methods (correlation of extent of lesions was 0.694 and nonsignificant difference on paired nonparametric analyses), there was not perfect consistency in every pair. Given the infinite variability of the human brain, attempting "perfect" matches between any two injured brains is a lofty but probably unattainable goal. Future researchers may wish to expand and refine our method to attempt even more rigorous matching procedures, possibly incorporating lesion location and lesion volume.

Research on age at onset of childhood brain lesions and cognitive outcomes could potentially clarify the issue of neural plasticity if consistent relationships were documented between age at onset and outcomes, such as was initiated in the animal work conducted by Hubel and Weisel[6] documenting "critical periods" of neural development. Unfortunately, the relevant adult data in the extant literature do not serve to clarify the issue much because the findings are mixed. Some studies have found no significant influence of age at onset of childhood lesions,[46,47] and some have found a U-shaped IQ distribution (children with congenital and late lesions having higher IQ scores than children with middle childhood lesions).[23,24,48] Taking into account both age at onset and side of lesion, Hogan et al[22] presented data from an ongoing project that suggest that early lesions (acquired before age 5) do not lead to a dissociation between Verbal and Performance IQ based on hemispheric location. Lesions acquired after age 5 begin to show lateralization, with the relative preservation of Verbal IQ in right hemisphere cases and lower Verbal and Performance IQ in left hemisphere cases. Aram,[9] in a review of studies examining age at lesion onset as a predictor of subsequent cognitive impairment, concluded that there is not a strong relationship between the age at which children's lesions are acquired and performance on cognitive tasks. Rather, there appears to be a modest relationship suggesting that lesions acquired very early (eg, before the age of 1) lead to poorer outcome than childhood lesions acquired later.

Our research did not address the issue of age at onset except in a very general manner, such that children and adults were separate groups for quantitative and qualitative statistical analysis. Further research on this topic might explore this issue by examining age at onset within each group as an independent variable, either as a continuous variable or a categorical variable (eg, "early" lesions defined as acquired at younger than 1 year versus "middle" and "late" childhood lesions). Because of our somewhat small sample sizes, we did not approach our data in this manner as we would have significantly lost statistical power by further dividing our child and adult subjects into smaller groups.

Another possibly pertinent issue that was not specifically addressed in our research is whether lesion location as divided into "cortical-only" or "subcortical-only" categories leads to the finding of differential neuropsychological effects. Relevant data from Aram and Ekelman[16,49] suggest that children with subcortical-only lesions (as opposed to cortical-only lesions) tend to be more impaired, with left hemisphere subcortical–lesioned children having lower Verbal IQ scores (relative to Performance IQ) and right hemisphere–lesioned children having lower Performance IQ scores (relative to Verbal IQ). Review of these studies and others led Aram[9] to conclude that children with left hemisphere lesions confined to subcortical structures show persistent and severe deficits in academic skills acquisition. In contrast, Hogan et al[22] reviewed evidence to raise the possibility that cortical damage was more detrimental than subcortical damage, although when size of lesion was taken into account, this effect became questionable. Again, our limited sample sizes prevented further analysis along these lines, as many of our subjects had both cortical and subcortical involvement and thus subgroups of "cortical-only" and "subcortical-only" subjects would have been quite small.

In conclusion, the most interesting and compelling overall finding from this research is the degree of similarity between outcomes of adults and children with carefully matched brain lesions who are studied years after lesion onset. Although there is some evidence of adult plasticity in the existing literature, this was a somewhat unexpected finding, given that much of the previous work in the area suggested that children might show more resiliency after brain damage than adults with similar brain damage. Our approach of lesion matching based on location and size is a novel one that was used to further illuminate this issue and highlights the similarity in plasticity between immature and mature nervous systems. We hope the method will provide fodder for future research and debate in this exciting arena.

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