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Object-based visual processing in children with spina bifida and hydrocephalus: A cognitive neuropsychological analysis

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The aim of the study was to use cognitive neuropsychological analysis to investigate object-based visual processing skills in children with spina bifida myelomeningocele and hydrocephalus (SBH). Fourteen children with SBH (aged 8–12) and 21 age-, socio-economic status-, and Verbal IQ-matched healthy controls were assessed using the Birmingham Object Recognition Battery. Overall, the performance of the children with SBH on the object-processing tasks was intact, indicating normal development of the ventral visual processing pathway. While the initial results indicated that the children with SBH performed statistically significantly less accurately on some tasks, these group differences no longer met significance criteria after capacity for sustained attention was statistically controlled.

Spina bifida is a congenital defect of neural tube closure in early embryogenesis. It manifests as a malformation along the spinal cord and can occur at any point from the cervical to lower sacral regions. It is a common, severely disabling birth defect with current prevalence levels in North America of 0.3–0.5 per 1,000 births (post-dietary fortification data; Williams, Rasmussen, Flores, Kirby, & Edmonds, 2005). The most severe, and the most common, form of spina bifida is myelomeningocele and this occurs when the spinal cord protrudes through the midline defect. Most children with spina bifida also have brainstem and cerebellar malformations (the Arnold-Chiari II malformation) that frequently obstruct the outflow of cerebrospinal fluid from the ventricles, resulting in hydrocephalus. A progressive form of hydrocephalus, requiring diversionary shunting, occurs in 80–90% of cases of spina bifida myelomeningocele (Anderson, Northam, Hendy, & Wrennall, 2001). The hydrocephalus leads to stretching and thinning of the cortex, particularly in posterior regions and the corpus callosum.

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As such, spina bifida myelomeningocele with hydrocephalus (SBH) represents a complicated series of neural insults that begins prior to birth, with persisting effects on development, including problems in the orthopaedic, cognitive, and behavioural domains (Anderson, 1973; Anderson *et al.*, 2001; Fletcher, Dennis, & Northrup, 2000; Fletcher *et al.*, 2004; Wills, 1993).

Numerous studies have documented that children with SBH have poor visual perceptual skills. Early studies indicated that when comparisons were made within SBH groups, performance IQ (PIQ) scores were lower than verbal IQ (VIQ) scores (Dennis *et al.*, 1981; Donders, Rourke, & Canady, 1991; Fletcher *et al.*, 1992; Jamison & Fee, 1978; Lonton, 1977; Riva *et al.*, 1994; Shaffer, Friedrich, Shurtleff, & Wolf, 1985; Wills, Holmbeck, Dillon, & McLone, 1990). However, it is noted that a recent study utilizing a more recent version of the Wechsler (1992) Intelligence Scales for Children failed to find a significant discrepancy between Verbal and Performance Scale scores (Jacobs, Northam, & Anderson, 2001). In addition, a more recent study of adolescents and young adults with SBH also failed to find any statistically significant discrepancy between Verbal and Performance Scale scores (Hommet *et al.*, 1999).

Bearing in mind the limitations of utilizing the Wechsler scales in isolation to investigate the visual perceptual skills of children with SBH, further research has investigated these skills in closer detail with broader test batteries. The results of these studies indicated that when comparisons were made between SBH and control groups, or between SBH groups and published test norms, children with SBH performed more poorly on visual perception tasks such as copying geometric figures or patterns, drawing people, matching patterns, disembedding figures, and perceiving multistable figures that involve figure-ground reversals, illusory contours, perspective reversing, and paradoxical figures (Dennis, Rogers, & Barnes, 2001; Friedrich, Lovejoy, Shaffer, Shurtleff, & Beilke, 1991; Sand, Taylor, Rawlings, & Chitnis, 1973; Sandler, Macias, & Brown, 1993; Soare & Raimondi, 1977; Willoughby & Hoffman, 1979; Wills *et al.*, 1990).

In keeping with the previous literature, the results of a more recent study conducted by Dennis, Fletcher, Rogers, Hetherington, and Francis (2002) also found that children with SBH performed poorly on a range of visual perception tasks. However, following the work of Milner and Goodale (1995), this study employed a theoretical framework to guide test selection, and administered tests of both 'ventral stream' (object-based) visual perception and 'dorsal stream' (action-based) visual perception to further investigate the visual perceptual skills of these children. The results of this study contributed three new pieces of information to the previous literature. These were that children with SBH and no significant intellectual impairment: (1) performed as well as age-matched controls on some visual perception tasks, such as face recognition; (2) performed relatively better on tasks requiring ventral stream (object-based) visual processing than on tasks requiring dorsal stream (action-based) visual processing; and (3) perform comparably on tasks requiring multistable representations of visual space or visually guided action.

It is highlighted that although finding (2) indicated that children with SBH perform object-based (ventral) visual processing tasks better than action-based (dorsal) visual processing tasks, close inspection of the results revealed that the children with SBH were performing significantly less efficiently than the controls ($p < .05$) on a number of those ventral processing tasks. In particular, they performed significantly less efficiently on tasks of object identification and line orientation and the effect sizes (ESs) for these tasks were moderate to large (Cohen, 1988). These specific difficulties in object-based visual processing warrant further investigation and were the focus of the current study.

Cognitive neuropsychological analysis

To further investigate these specific difficulties with object-based (ventral stream) visual perception, a cognitive neuropsychological approach can be applied. Such an approach is increasingly being used in the analysis of developmental and acquired disorders of numerous cognitive domains. The methodology can be applied in either (a) individual case studies or (b) group studies, where, for example, a genetic disorder may be associated with a specific pattern of skill dissociation which could be interpreted in relation to the common functional architecture (Temple, 1997; Temple, Almazan, & Sherwood, 2002; Temple & Carney, 1995, 1996; Temple, Carney, & Mullarkey, 1996; Temple & Marriott, 1998; Temple & Sanfilippo, 2003). The cognitive neuropsychological approach involves the development of elaborated models of specific cognitive functions that allow for the differentiation of the specific cognitive processes involved. Such models emphasize separate serial processing of specific components via a series of modules and pathways. According to most models, processing usually takes place in a hierarchical manner.

A functional model of object-based visual processing was proposed by Ellis and Young (1988), based on the work of Marr (1982) (see Figure 1). The first-level of this model describes early perceptual analysis, followed by selective processing of object characteristics, access to stored knowledge about objects and, finally, object naming. Evidence to support cognitive models, such as the model depicted in Figure 1, has come from the study of acquired disorders in the fully matured, adult system. While this has led to considerable theory development and debate, there has been little attention paid to developmental issues or the manifestation of these disorders in childhood (Joy & Brunsdon, 2002).

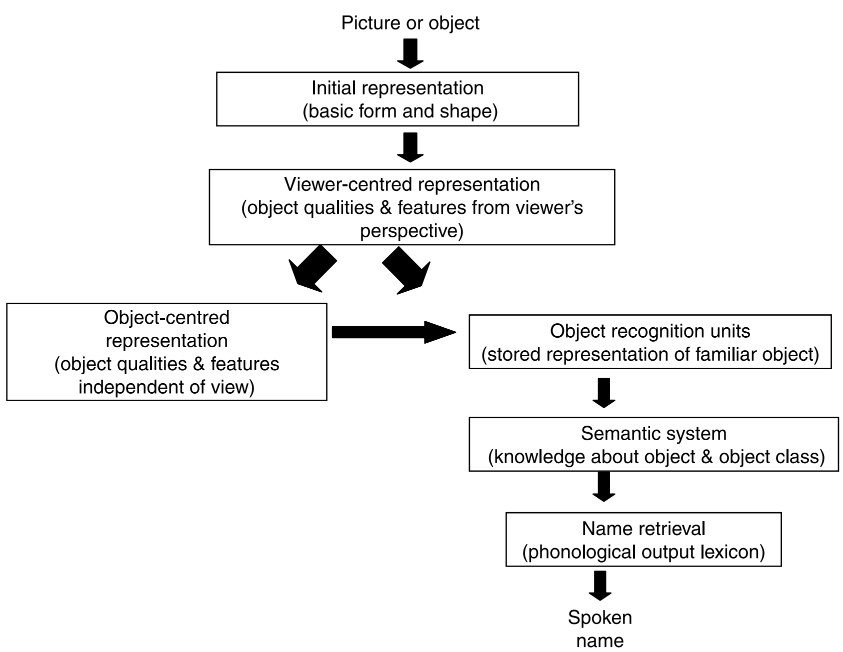

Figure 1. Model of early visual perceptual analysis and visual object recognition. Adapted from Ellis and Young (1988, p. 31).

A similar cognitive model of object-based visual processing formed the theoretical basis for the design of the Birmingham Object Recognition Battery (BORB; Riddoch & Humphreys, 1993). This battery consists of 14 tasks that assess the various components of early visual perceptual analysis, visual object recognition, and object naming. The BORB was normed on brain-damaged and healthy control adults, and there is currently limited data available on how children perform on this test. Joy and Brunsdon (2002) utilized this battery of tests in their case study of A. L., a young boy with prosopagnosia and visual processing deficits of presumed developmental origin. The data from the small age-matched comparison group used in that study suggested that children as young as 6 years were performing at or near adult levels on many of the BORB tasks. For example, the controls displayed a narrow range of scores on the perceptual analysis tasks (BORB tasks 2–4) suggesting that by age 7, there is little developmental variability in the capacity to process information about length, size, and orientation. With the exception of this case study, however, there appear to have been no studies investigating the normal development of object-based visual processing skills.

Study aims

Following on from the study of Dennis *et al.* (2002), the overall aim of this study was to further explore the object-based visual processing skills of children with SBH utilizing a cognitive neuropsychological group study approach. In detail, the first aim of the current study was to investigate whether the visual object processing deficits previously seen in children with SBH are explicable against a cognitive model of object-based visual processing ('ventral' pathway) proposed in the adult literature (Ellis & Young, 1988) as assessed using the BORB (Riddoch & Humphreys, 1993).

The second aim of the current study was to examine the impact of attention on performance on these visual processing tasks as previous studies have documented significant impairments in attention in children with SBH (Brewer, Fletcher, Hiscock, & Davidson, 2001; Loss, Yeates, & Enrile, 1998). In addition, a number of recent studies have reported that the incidence of developmental attention-deficit/hyperactivity disorder (ADHD) in their sample of ADHD children exceeded the population rate, with most children with SBH and ADHD meeting criteria for the predominantly inattentive type (Burmeister *et al.*, 2005; Fletcher *et al.*, 2005). Our own research has replicated these previous findings and indicated that children with SBH display significant impairment of the four components of attention proposed by Mirsky, Anthony, Duncan, Ahearn, and Kellam (1991), being *Encode*, *Focus/Execute*, *Sustain*, and *Shift* (Swain, Joy, Bakker, Shores, & West, 2006). However, it is highlighted that the attention component which best separated the SBH and control groups in our research was *Sustain*, with the results confirming that children with SBH demonstrate clinically significant impairment of sustained attention. Therefore, a measure of *Sustain* was used to statistically control for the impact of difficulties with sustained attention and investigate whether these difficulties were impacting on the performance of the children with SBH on the visual processing tasks of the BORB.

Method

Participants

Sixteen children between the ages of 8 years 0 month and 12 years 1 month were recruited from the Spina Bifida Unit of the Rehabilitation Department at The Children's

Hospital at Westmead, Sydney, Australia. Children with SBH were selected to participate in the study if myelomeningocele had been diagnosed at birth, and hydrocephalus diagnosed at that time or shortly thereafter and treated with a shunt. Exclusion criteria operated such that children with a prior history of traumatic brain injury or epilepsy were not eligible for participation. Following interview and testing, the assessment results for two children were excluded from statistical analysis, providing a sample of 14 participants with SBH. The first child excluded from the statistical analysis had been diagnosed with SBH and treated with a shunt; however, he had experienced seizures and undergone shunt revision surgery during the fortnight prior to the assessment. The second child excluded from the statistical analysis was found to have a history of epilepsy in addition to SBH. The medical characteristics of 12 of the 14 SBH participants are shown in Table 1.

Table 1. Medical characteristics of SBH group

	Frequency (*N*)	Percentage
Level of myelomeningocele		
Cervical	0	0
Thoracic	3	21.4
Lumbar	9	64.3
Sacral	0	0
Side of shunt		
Right	12	85.7
Left	0	0
Bilateral	0	0
Number of shunt revisions		
None	5	35.7
One	5	35.7
More than one	2	14.3

Note. Medical characteristics for two SBH participants were unavailable.

Twenty-three healthy children aged 8 years 2 months to 11 years 10 months, selected to closely match with participants in the SBH group for age, socio-economic status (SES) and VIQ, were recruited from a local primary school to participate as controls in the study. Exclusion criteria operated such that children with a history of neurological disorder or developmental ADHD were not eligible for participation. Following testing, the assessment results for two children were excluded from statistical analysis, providing a sample of 21 healthy control participants. Both children excluded from statistical analysis were found to have a history of developmental ADHD that was being treated with stimulant medication. SES was determined for each child using the Daniel's (1983) Scale of Occupational Prestige on which parental occupation is rated between 1 and 7, with a score of 1 reflecting high SES and a score of 7 indicating low SES.

Measures

All participants were administered the following tests in the same order:

Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999). The children were administered the four-subtest form of this test battery to (a) provide an estimate of each child's level of verbal intellectual functioning (VIQ) for the purposes of matching the clinical and control samples, and (b) to investigate whether the SBH group displayed any significant discrepancy in the development of their verbal (VIQ) and non-verbal (PIQ) intellectual abilities.

Test of Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1999). As part of a larger study of neuropsychological functioning of children with SBH, each child was administered the Score! subtest from the TEA-Ch (Swain *et al.*, 2006). Structural equation modelling indicated that this subtest was associated with a sustained attention factor (Manly *et al.*, 1999). In each of the 10 items of the subtest, between 9 and 15 identical tones of 345 ms are presented, separated by silent inter-stimulus intervals of variable duration (between 500 and 5,000 ms). The child was asked to silently count the tones (without assistance from fingers) and to give the total at the end. The duration of the test was approximately 5 min 40 s. Raw scores were converted to age-scaled scores (ASS) using the TEA-Ch manual.

BORB (Riddoch & Humphreys, 1993). This battery of tests is composed of 14 tasks designed to assess the cognitive processes involved in visual processing and object recognition. There is no information provided in the BORB manual regarding psychometric properties. Twelve of the fourteen tasks were administered in the current study, and are described below. They have been grouped together according to the cognitive processing module they are purported to assess. The two tasks not administered were BORB Test 1, a copying task, and BORB Test 9, a drawing from memory task. These drawings tasks were not included due to the difficulties in generating an objective score for each task for each participant.

Initial representation

BORB Tests 2–5: Perceptual matching tasks. The child was required to say whether two items were the 'same' or 'different' with regard to the stimulus features of length, size, orientation, and position. There were 30 items in BORB Tests 2–4 (B2–B4) and 40 items in BORB Test 5 (B5).

Viewer-centred representation

Test 6 (B6): Overlapping figures task BORB. The child was required to name all the items presented on a page. For each stimulus set (paired letters, triplet letters, and paired line drawings), the items were firstly presented as non-overlapping stimuli. The items were secondly presented as overlapping stimuli, where recognition of the items required perceptually segmenting each item from another. Performance on this task was timed. A 'ratio score' for each stimulus set (paired letters, triplet letters, and paired line drawings) was calculated to indicate the relative difference between naming in the overlapping and non-overlapping conditions.

Object-centred representation

BORB Tests 7 and 8: Recognition across different viewpoints. The child was presented with a standard view of a target object and then required to match one of two objects, shown in a different view, with the target object. This assessed the ability of the child to recognize objects presented from different viewpoints. There were 25 items in both tests (B7 and B8).

Object recognition units

BORB Test 10: Object decision task (A: Hard and B: Easy). The child was asked to determine whether line drawings of animals and tools were 'existing' or 'non-existing'. The 'non-existing' stimuli were constructed by replacing one feature of a real object with a feature from another object within its superordinate category (for example, substituting parts of two tools to create an 'non-existing' tool or substituting parts of two animals to create an 'non-existing' animal). Half of the non-existing stimuli were visually similar to their existing counterpart (for example, a tortoise with a snake's head), half were selected to be visually dissimilar (for example, a mouse's head on a zebra's body). The 'existing' stimuli were divided into two sets:

(1) The 'existing' stimuli in the first set were paired with visually dissimilar 'non-existing' counterparts (BORB Test B: easy (B10B)). There were 32 items in this set.
(2) The 'existing' stimuli in the second set were paired with visually similar 'non-existing' counterparts (BORB Test 10 A: hard (B10A)). There were 32 items in this set.

Semantic system

BORB Tests 11 and 12: Item match and associative match tasks. The child was required to choose (a) which one of two pictures came from the same category as the target picture (Test 11) and (b) which one of two pictures is more closely associated with the target picture (Test 12). There were 32 items in BORB Test 11 (B11) and 30 items in BORB Test 12 (B12).

Name retrieval

BORB Tests 13 and 14: Picture naming tasks. For BORB Test 13 (B13), the child was required to name 15 low-frequency animate drawings and 20 low-frequency inanimate drawings. *Note*. The word 'cup' was considered an acceptable alternative to the word 'glass' when assessing Australian children. For BORB Test 14 (B14), the subject was required to name 76 pictures, half of which come from categories with exemplars that have similar perceptual properties ('structurally similar objects', mostly belonging to animate categories) and half of which come from categories with exemplars that have dissimilar perceptual structures ('structurally dissimilar objects', mostly belonging to inanimate categories). Note: The word 'shirt' was considered an acceptable alternative to the word 'blouse' when assessing Australian children.

Procedure

The results published in this paper are from a larger study of neuropsychological functioning in children with SBH. For participants with SBH, a letter was sent to the parents of eligible children, describing the study and inviting them to participate, as per ethics procedure. Once signed consent was obtained, all children were assessed in a quiet setting, either in their own home or at The Children's Hospital at Westmead, over one session. For healthy control participants, a local school was contacted and consent obtained for participation in the study. With the assistance of the school principal, children were selected to match the clinical group as closely as possible with respect to age and level of verbal intellectual functioning. Parents of identified children were contacted by letter with an invitation for their child to participate in the study. Upon return of signed consent forms and demographic questionnaires, children were assessed at school in the same manner as the clinical sample.

Statistical analysis

Statistical analysis was conducted using SPSS version 11.0 for Mac OS X. Preliminary analyses were conducted using independent samples *t* tests to investigate group differences in scores on each measure to determine if the SBH group demonstrated impairment in comparison to the control group on the particular task. All data was analysed using an alpha level of .05. While this is a lenient alpha level given the number of tasks administered, it was considered reasonable to ensure a balance between Type 1 and 2 error rates given the small sample sizes.

To further explore group differences and following the recommendations of Zakzanis (2001), the data from each BORB task was also used to calculate an ES. This provided a common metric across tasks qualifying how much the SBH and control groups differed. The ES statistic, *d* (Cohen, 1988), is the difference between the means for the group of interest (in this case, the SBH group) and a control group in standard score form. Comparisons of *d* provide a direct method of examining the magnitude of the differences between groups on different tasks independent of the sample size which influences the results of traditional parametric tests. Conventional definitions of ESs were offered by Cohen (1988): $d = 0.20$ (small), $d = 0.50$ (medium), and $d = 0.80$ (large). An overlap statistics (OL%) was also calculated from Cohen's *d*. This OL% reflected the amount of overlap in the distribution of test measure scores between the SBH and healthy control groups, with less overlap indicating greater separation of the two groups.

To examine the impact of attention on performance of the BORB visual processing tasks, analyses of covariance (ANCOVAs), comparing the results of the SBH group with the healthy control group (with capacity for sustained attention covaried), were also performed on the raw scores. All data were analysed using an alpha level of .05.

Results

Demographic data

The results of independent samples *t* tests indicated that the SBH group and the healthy control group did not differ significantly on the variables of age (in months), SES or VIQ, indicating a well-matched sample. In contrast to much previous research but consistent with more recent studies (Hommet *et al.*, 1999; Jacobs *et al.*, 2001), no statistically significant discrepancy between the Verbal and Performance Scale scores in favour of VIQ was found within the SBH group ($t(13) = 1.06$, $p > .05$). However, the mean full scale IQ (FSIQ) and PIQ scores of the SBH group was statistically significantly lower than the mean FSIQ and PIQ scores of the control group and were rated in the low average range. In addition, the mean score of the SBH group on the Score subtest from the TEA-Ch, measuring capacity for sustained attention, was statistically significantly lower than that of the control group ($t(32) = 3.48$, $p < .05$). Group demographic means and statistical comparisons are presented in Table 2.

Table 2. Demographic characteristics

	SBH ($N = 14$)	Control ($N = 21$)	Comparison
Mean age (months)	129.14 (14.86)	121.76 (14.70)	$t(33) = 1.45, p = .16$
Mean SES rating	4.61 (1.06)	4.79 (1.00)	$t(33) = 0.52, p = .61$
Mean VIQ	86.50 (16.82)	90.71 (12.39)	$t(33) = 0.85, p = .40$
Mean PIQ	81.43 (15.72)	96.10 (13.08)	$t(33) = 3.00, p = .01^*$
Mean FSIQ	82.50 (14.38)	92.86 (12.20)	$t(33) = 2.29, p = .03^*$
Mean attention ASS	5.71 (3.73)	10.00 (3.39)	$t(32) = 3.48, p = .00^{**}$

Note. Scores listed are mean scores with standard deviations in brackets. Comparisons are *t* statistics for independent samples *t* tests comparing the SBH subject's scores to healthy control subject's scores. Levene's tests for homogeneity of variance were not significant indicating that there were no significant differences between the variances of the groups and therefore the equal variance estimates were interpreted. Mean attention ASS = mean age-scaled score on Score subtest from the TEA-Ch.
$^*p < .05$; $^{**}p < .01$.

Object-based visual processing in children with SBH

Table 3 presents group mean scores, ESs, and OL% for the BORB subtests. It should be noted that not all children completed all of the selected BORB subtests because some refused some tasks and this has resulted in missing data. Exact sample sizes for each BORB subtest are noted in Table 3.

Initial representation

Analysis of BORB task performance indicated that the children with SBH performed statistically significantly less accurately than the healthy control children on one of the perceptual matching tasks that required them to match stimuli for length (B2) ($t(32) = 2.24, p < .05$). Further analysis of this result indicated that the ES (Cohen's d) for this task was 0.79 which can be interpreted as a large effect using Cohen's (1988) frame of reference. This large effect corresponds to approximately 52.6% overlap in the distribution of test scores between the SBH and healthy control groups. Therefore, approximately 47.4% of the children with SBH obtained a score that was unlike any of those obtained by the healthy control children on this task.

Further analysis revealed no statistically significant group differences in performance on the size, orientation, and position of gap matching tasks. However, the ES for the orientation matching task (B4) was 0.80 which could also be interpreted as a large effect (Cohen, 1988) and corresponded to approximately 52.6% overlap in the distribution of test scores between the SBH and healthy control group. A similarly moderate to large ES of 0.68 was obtained for the size matching task (B3) which corresponded to approximately 57% overlap in the distribution of test scores between the SBH and healthy control group.

Viewer-centred representation

There were no statistically significant differences between the performances of children with SBH and healthy control children on BORB Test 6, which assessed the ability of the children to perceptually segment one item from another.

Table 3. Mean performance on BORB visual processing tasks

	SBH ($N = 14$)	Control ($N = 21$)	Comparison	d	OL%
Initial representation					
B2: length match (/30)	23.62 (3.18)[a]	25.67 (2.18)	$t(32) = 2.24$, $p = .03^{*}$	0.79[c]	52.6
B3: size match (/30)	22.38 (3.55)[a]	24.24 (2.14)	$t(32) = 1.91$, $p = .07$	0.68	57.0
B4: orientation match (/30)	21.38 (3.71)[a]	23.67 (2.22)	$t(17) = 2.00$, $p = .06$	0.80[c]	52.6
B5: position match (/40)	30.23 (4.05)[a]	31.52 (4.23)	$t(32) = 0.88$, $p = .39$	0.31	78.7
Viewer-centred representation					
B6: overlapping figures					
Paired letters	1.15 (0.14)[a]	1.26 (0.24)[b]	$t(31) = 1.46$, $p = .16$	0.52	66.6
Triplet letters	1.09 (0.14)[a]	1.11 (0.14)[b]	$t(31) = 0.36$, $p = .72$	0.13	92.3
Paired drawings	1.14 (0.20)[a]	1.12 (0.26)[b]	$t(31) = 0.18$, $p = .86$	0.06	92.3
Object-centred representation					
B7: min. feature view (/25)	24.15 (1.57)[a]	24.62 (0.50)	$t(14) = 1.04$, $p = .32$	0.45	66.6
B8: foreshortened view (/25)	24.00 (1.08)[a]	24.29 (0.64)	$t(32) = 0.97$, $p = .34$	0.35	72.6
Object recognition units					
B10: object decision					
A: hard (/32)	22.23 (3.63)[a]	24.29 (2.59)	$t(32) = 1.93$, $p = .06$	0.68	57.0
B: easy (/32)	29.62 (1.85)[a]	29.81 (1.60)	$t(32) = 0.32$, $p = .75$	0.11	92.3
Semantic system					
B11: item match (/32)	31.29 (1.14)	32.00 (0.00)	$t(13) = 2.35$, $p = .04^{*}$	0.99[c]	44.6
B12: associative match (/30)	26.93 (2.27)	28.19 (1.72)	$t(33) = 1.87$, $p = .07$	0.64	61.8
Name retrieval					
B13: picture naming					
LF animate (/15)	12.21 (2.55)	13.00 (1.05)	$t(16) = 1.09$, $p = .29$	0.44	72.6
LF inanimate (/20)	18.00 (1.73)[a]	18.19 (1.21)	$t(32) = 0.38$, $p = .71$	0.13	92.3
B14: picture naming (/76)	61.43 (8.44)	63.76 (5.19)	$t(33) = 1.02$, $p = .32$	0.35	72.6

Note. Scores listed are mean raw scores with standard deviations in brackets. Scores listed for B6 are ratio scores reflecting *relative* differences between naming in the overlapping and non-overlapping conditions (measured per item in seconds). Comparisons are *t* statistics for independent samples *t* tests comparing the SBH subject's scores to healthy control subject's scores. The assumption of homogeneity of variance was violated for tests B4, B7, B11 and B13 (low-frequency animate); therefore, the unequal variance estimates were interpreted.
[a] $N = 13$; [b] $N = 20$; [c] Large ES; $^{*}p < .05$.

Object-centred representation

Analysis of the results revealed no statistically significant differences between the performance of the children with SBH and healthy control children on BORB Tests 7 and 8, which assessed the ability of the children to recognise objects presented from different viewpoints.

Object recognition units

Analysis of the results indicated no statistically significant differences between the performance of the children with SBH and the healthy control children on BORB Test 10, which assessed their ability to access stored representations of familiar objects.

Semantic system

BORB Test 11 assessed the children's semantic knowledge of objects, including knowledge of object class. While the healthy control children performed at ceiling on this test, the children with SBH performed statistically significantly less accurately ($t(13) = -2.35, p < .05$). However, given that the SBH group obtained a mean score of 31.29 out of 32, and there was a small standard deviation of 1.14, this result was not considered to be clinically significant. In support of this, further assessment indicated that there was no statistically significant difference in performance between the two groups on BORB Test 12, which also assessed access to semantic knowledge about objects.

Name retrieval

Statistical analysis revealed no significant difference between the abilities of the children with SBH and the healthy control children to retrieve the names of pictures of objects.

Impact of attention on performance on object-based visual processing tasks

To examine the impact of attention on performance on the visual processing tasks where statistically significant differences were found, ANCOVAs, comparing the results of the SBH group with those of the healthy control group (with capacity for sustained attention covaried), were performed on the BORB raw scores. The *F*-statistics with corresponding *p*-value are shown in Table 4. The results indicated that when attention was statistically controlled for, the SBH children's performance on the length match and item match tasks was no longer statistically significantly less accurate than the performance of the healthy control children.

Table 4. The impact of attention on performance on object-based visual processing tasks

	Comparison
B2: length match	$F(1, 30) = 1.75, p = .20$
B11: item match	$F(1, 31) = 3.83, p = .06$

Note. Tests for homogeneity of regression slopes were not significant indicating that the relationship of the dependent variable to the covariate was the same in each group.

Discussion

Overall, the performance of the children with SBH on the visual processing tasks of the BORB was intact, indicating normal development of the object-based (ventral) visual pathway despite damage to the posterior brain resulting from SBH.

The results of the study conducted by Dennis *et al.* (2002) had also indicated that children with SBH perform relatively better on tasks requiring ventral stream (object-based) visual processing than on tasks requiring dorsal stream (action-based) visual processing. However, the children with SBH in that previous study had performed significantly less accurately than the controls on two of the object-based visual perception measures (line orientation and object identification). The results of this current study, which included a detailed cognitive neuropsychological analysis of the object-based visual processing skills of children with SBH, confirmed that the ventral stream visual processing skills of children with SBH are intact; however, the results failed to replicate the statistically significant inefficiency on line orientation and object identification tasks found in the Dennis *et al.* (2002) study. It is acknowledged that the differences in results between the two studies may reflect differences in task difficulty and that further studies are required to confirm that the ventral-based visual processing stream is intact in children with SBH. It is noted that the results of the current study did indicate a large ES (Cohen, 1988) for the BORB orientation match task (B4), which also assessed the ability to accurately judge line orientation. In addition, the results of the current study detected a statistically significant difference between the performance of the SBH and control groups on the BORB length match task (B2), which also corresponded to a large ES (Cohen, 1988). Both of the tasks formed part of the *initial representation* module in the cognitive model of object-based visual processing (Ellis & Young, 1988). These results suggested that children with SBH may have displayed a relative weakness in forming an accurate initial representation of visual stimuli, in the context of otherwise intact higher-level ventral stream visual processing. This finding was a possible challenge to the proposed hierarchical nature of the Ellis and Young model which implies that impairment in low-level visual perception tasks should also have a significant impact on performance on the higher-level object-processing tasks (such as the tasks assessing visual object recognition and object naming).

However, on further analysis of the results, it was found that when capacity for sustained attention was statistically controlled (the second aim of the study), any statistically significant differences between SBH and control groups on the object-processing tasks no longer met significance criteria. This was a crucial finding and highlighted the importance of controlling for attention variables when assessing children with SBH on various cognitive domains and the importance of controlling for other potentially significant covariates when employing cognitive neuropsychological methodology. This finding also indicated that attention difficulties were the most likely contributor to the relative weakness in the low-level ability to form an accurate initial visual representation in the context of otherwise intact higher-level ventral stream visual processing.

The results of this study have highlighted that the object-based visual processing skills of children with SBH are intact; however, the action-based visual processing skills of these children were not examined due to the lack of availability of a cognitive neuropsychological test battery systematically assessing these skills at the time the study was conducted. In the future, further research utilizing a cognitive neuropsychological approach to understand the deficits in dorsal stream visual processing reported by Dennis *et al.* (2002) is required. It is possible that the wide range of deficits in visual perception that were reported in earlier studies (Dennis *et al.*, 2001; Friedrich *et al.*, 1991; Sand *et al.*, 1973; Sandler *et al.*, 1993; Soare & Raimondi, 1977; Willoughby & Hoffman, 1979; Wills *et al.*, 1990) may reflect underlying deficits of the action-based visual processing stream. A detailed cognitive neuropsychological model of action-based visual processing has not yet, to our knowledge, been developed and would be an important contribution to the literature to help us to further understand deficits of the dorsal processing stream. In addition, further research into the neuropathological basis of these deficits in dorsal stream processing is required. As Dennis *et al.* (2002) highlighted, the contribution of the dysmorphologies of the cerebellum, midbrain and tectum, corpus callosum, and posterior cortex typically seen in children with SBH to these spatial deficits requires further study and integration of both neuroimaging and functional measures.

With regard to Ellis and Young's (1988) model of object-based visual processing, the results of the current study indicated that the object-based visual processing skills of children with SBH were intact and were not highlighted by any specific impairment in any of the modules of the proposed model. The finding that the relative weakness in the lower-level module of the model was no longer statistically significant after controlling for attention indicated that the results of the current study provide no evidence in dispute of the proposed hierarchical nature of the cognitive model. While the higher-level object processing tasks did require capacity for sustained attention, it could be argued that they were more intrinsically interesting and engaging for the children than the low-level visual perceptual tasks and therefore less susceptible to the attention difficulties and distractibility of the children with SBH. Overall, the cognitive model provided a sound theoretical framework for detailed assessment and interpretation of the object-based visual processing skills of the children with SBH.

It is acknowledged that the study is characterized by several limitations. While the results of the current study indicate that the ventral stream visual processing skills of children with SBH are largely intact, as assessed using the subtests of the BORB and when compared with control children of matched VIQ, further research utilizing other valid and reliable measures of object-based visual processing is required. These measures need to be specifically designed for children and provide developmental normative information. This is particularly important given that no developmental normative or psychometric properties were provided with the BORB manual. In addition, it is acknowledged that the lack of differences between the children with SBH and the control group reported in this study may be related to lack of power given that there were only 14 participants in the SBH group. Therefore, further studies replicating this cognitive neuropsychological approach with larger samples of children with SBH over a wider age group is also required. Further studies utilizing a measure of visual sustained attention, as opposed to the measure of auditory sustained used in the current study, would also be beneficial to confirm the impact of attention difficulties on the visual processing skills of children with SBH.

Despite these limitations, the findings may hold several potential clinical implications. The first is that the ventral visual processing stream of children with SBH is intact. Therefore, the focus of clinical neuropsychological assessment of the visual processing skills of these children, and subsequent intervention, should be on the functions of the dorsal visual processing stream which has been reported to be compromised in these children (Dennis *et al.*, 2002). The second clinical implication is that the impact of the attention difficulties that these children display (Brewer *et al.*, 2001; Loss *et al.*, 1998; Swain *et al.*, 2006) should always be taken into account when interpreting the findings of clinical neuropsychological assessment of these children. These attention difficulties should always be the focus of targeted intervention when case managing these children.

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