

Object-based and action-based visual perception in children with spina bifida and hydrocephalus

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Abstract

Children with spina bifida and hydrocephalus (SBH) have long been known to have difficulties with visual perception. We studied how children with SBH perform 12 visual perception tasks requiring object identification, multistable representations of visual space, or visually guided overt actions. Four tasks required object-based processing (visual constancy illusions, face recognition, recognition of fragmented objects, line orientation). Four tasks required the representation of visual space in egocentric coordinates (stereopsis, visual figure-ground identification, perception of multistable figures, egocentric mental rotation). Four tasks required the coupling of visual space to overt movement (visual pursuit, figure drawing, visually guided route finding, visually guided route planning). Effect sizes, measuring the magnitude of the difference between SBH children and controls, were consistently larger for action-based than object-based visual perception tasks. Within action-based tasks, effect sizes were large and roughly comparable for tasks requiring the representation of visual space and for tasks requiring visually guided action. The results are discussed in terms of the physical and brain problems of children with SBH that limit their ability to build effective situation models of space. (*JINS*, 2002, 8, 95–106.)

Keywords: Visual perception, Spina bifida-Hydrocephalus, Ventral stream, Dorsal stream

INTRODUCTION

Children with spina bifida and hydrocephalus (SBH) have long been observed to have poor visual perception (e.g., Sand et al., 1973; Scherzer & Gardner, 1971). When comparisons are made within SBH groups, Performance IQ scores are lower than Verbal IQ scores (Dennis et al., 1981; Donders et al., 1990; Fletcher et al., 1992; Riva et al., 1994; Wills et al., 1990) and visual-perceptual age is lower than chronological age (e.g., Soare & Raimondi, 1977). When comparisons are made between SBH and control groups, or between SBH groups and published test norms, children with SBH perform more poorly on visual perception tasks such as disembedding figures, discriminating figure-ground, matching patterns, copying geometric figures or patterns, and drawing people (Anderson & Spain, 1977; Culatta, 1980;

Friedrich et al., 1991; Land, 1977; Miller & Sethi, 1971; Sand et al., 1973; Sandler et al., 1993; Simms, 1987; Soare & Raimondi, 1977; Willoughby & Hoffman, 1979; Wills et al., 1990).

Visual perceptual impairment is related to medical variability within spina bifida groups, such as the presence of hydrocephalus (Fletcher et al., 1992) and the need for shunting (e.g., Tew & Laurence, 1975). Impairment is also related to clinical status. Individuals with SBH have impaired upper limb function in childhood (Hetherington & Dennis, 1999) and also in young adulthood (Dennis et al., 2001), which affects the ability to perform visually guided hand and arm movements, such as those involved in drawing (Tew, 1991). Children with SBH, especially those with higher spinal cord lesions, have restricted mobility and opportunity for visual spatial and visuomotor learning (Sand et al., 1973; Simms, 1987). Many SBH children have eye movement disorders, which are associated with poor nonverbal and visual perceptual skills (Dennis et al., 1981; Friedrich et al., 1991; Lonton, 1977; Sand et al., 1973; Wills et al.,

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1990; Zeiner et al., 1985). For children with higher lesions, frequent hospitalizations for medical complications during developmentally sensitive periods might interfere with visual perceptual development (Soare & Raimondi, 1977).

For the most part, studies of visual perception in SBH have been descriptive rather than theoretically driven, providing little understanding of the nature of visual perception impairment or its neural substrate. Recent studies of the neural organization of visual perception, as well as recent studies identifying the brain dysmorphologies of SBH, provide the bases for hypotheses about the visual perception deficits in this population.

Neural Organization of Visual Perception

Visual perception involves the integrated and coordinated operation of processes that allow the individual to identify objects and to act, overtly or covertly, on the visual environment. The latter requires the representation of visual space in egocentric coordinates and the coupling of these coordinates to representations of (or actual) movement.

Object-based visual perception permits detection of features like contour, shape, size, and orientation, with respect to an allocentric, viewer-independent frame of reference intrinsic to the object (e.g., front, back, top, bottom). Action-based visual perception permits visually guided, goal directed action, and requires representations that are capable of multiple stable states and also egocentrically referenced relative to the effector systems involved in movement (Milner & Goodale, 1995; Paillard, 1991).

In everyday function, visual perception is coordinated; for example, spatial information about object location is required not only to direct action at objects but also to assign meaning to them. But object-based perception is memory based, and depends on matching what is seen against previous experience; people report the contents of this system when asked what they see (Bridgeman, 1999). For visual perception to be coupled to movement, it must be multistable, so visually guided behaviors do not need to be recalled, but rather, need to be momentarily stable and coordinated through multiple, stable states.

The cognitive organization of visual perception in brain-intact individuals is consistent with the distinction between object-based and action-based perception. The two visual systems have different expressions in infancy, and are asynchronous in development thereafter (Bertenthal, 1996). In adulthood, within-system covariation is greater than between system covariation (Chen et al., 2000). Even for illusory perception, the object perception required to match illusions is dissociable from the visual control of action required to grasp them (Daprati & Gentilucci, 1997; Otto-de Haart et al., 1999).

The neurophysiology of the primate visual system supports the distinction between object-based and action-based visual perception. Different single unit responses occur for different aspects of the same retinal image: Cells in cortical visual areas 1 and 2 and higher areas are segregated

into a pathway selective for form and color, derived from the parvocellular geniculate stream, and a pathway selective for depth and motion, derived from the magnocellular geniculate stream (Livingstone & Hubel, 1988).

Extrastriate visual cortical areas are organized into two anatomically distinct and functionally specified input pathways: a ventral occipital–temporal pathway for object identification independent of the observer, and a dorsal occipital–parietal pathway for perceiving stimulus properties such as direction of movement, important for spatial attention (Desimone & Ungerleider, 1990; Haxby et al., 1991; Maunsell & Newsome, 1987; Mishkin et al., 1983; Ungerleider & Mishkin, 1982). More recently, characterization of the dorsal visual system has emphasized visual input–output modules that enable on-line, real time control of the observer's actions within the visual world, including visually guided eye movements, transport, and visual grasp (Milner & Goodale, 1995).

The distinction between object-based and action-based visual perception has been validated in neurologically intact and neurologically compromised adults. Dorsal pathways are activated when healthy adults view meaningless actions to pantomime them, ventral pathways when they view the same actions to recognize them (Decety et al., 1997). Brain-injured individuals who are unable to recognize objects can nevertheless perform actions relevant to objects they fail to recognize, such as reaching, anticipating size and shape, and drawing (Farah, 1995; Goodale et al., 1991; Weiskrantz, 1986; Weiskrantz et al., 1974). Individuals with optic ataxia have defective control of visually guided movement but are able to identify objects (De Renzi, 1982).

The ventral object recognition system involves not only perception of, but also memory for, objects. The posterior inferotemporal cortex is concerned with visual object discrimination, the anterior portion with memory for visual information (Cowey & Gross, 1970; Iwai & Mishkin, 1969; Kikuchi & Iwai, 1980); accordingly, the degree of medial temporal lobe activation predicts how well a particular visual experience is encoded and hence, whether it will be remembered or forgotten (Brewer et al., 1998).

The parietal cortex represents visual space in multiple ways to encode locations of objects in several egocentric frames of reference (Colby & Goldberg, 1999) that include figure–ground delineation, discrimination of depth and contour, and changes in observer-referenced orientation. Parietal representations are linked to spheres of action. The posterior parietal cortex adjusts visually guided movements *via* a feedback system (Iacoboni, 1999). For example, transcranial magnetic stimulation to the posterior parietal cortex disrupts path corrections to moving (but not stationary) targets, suggesting that the posterior parietal cortex computes a dynamic motor error to correct an ongoing movement trajectory (Desmurget et al., 1999). Parts of the inferior parietal lobe, perhaps originally evolved for the overt control of movement, have developed visual–spatial algorithms that allow for the transformation and manipulation

of viewer-centered representations of the visual world, such as are important for spatial rotations, spatial imagery, the manipulation of spatial images, moving from one set of spatial coordinates to another, and visual motor planning (Milner & Goodale, 1995; Snyder et al., 1997).

The study of visual perception in adults has typically involved individuals with acquired lesions affecting either ventral or dorsal processing streams. How developmental anomalies of ventral and dorsal processing streams affect visual perception is not known. Children with spina bifida represent a population in which visual perception is a prominent deficit domain, and in which dorsal visual perception systems are more anatomically compromised than are ventral systems.

Brain Effects of SBH

Children with SBH have a range of primary brain dysmorphologies and secondary brain insults that affect the processing of visual information. They have disordered development of the midbrain and tectum (Lennerstrand et al., 1990) and widening of the third ventricle, which may compromise the structures in the upper brain stem that are involved in ocular vergence movements (Leigh & Zee, 1983), all of which would limit the magnocellular visual input required for the development of binocular vision, stereopsis, and depth perception (Lennerstrand, 1988). Children with SBH have significant cerebellar dysmorphology (Barkovich, 1995) which could further contribute to their eye movement and motor disorders. Characteristically, children with SBH and children with other forms of early hydrocephalus have a thin posterior (parietal–occipital) cortex relative to their own anterior cortex (Dennis et al., 1981; Fletcher et al., 1996), which further compromises magnocellular input to the action-based visual perception stream as well as the movement feedback system required to adjust movement to visual input. Agenesis and hypoplasia of the corpus callosum in SBH (Hannay, 2000) may further compromise complex visual motor integration.

Children with SBH have poor visual perception skills as well as specific brain dysmorphologies, and at least some of the brain and cognitive deficits are interrelated. For example, children with selective posterior cortical compromise have greater visual perception and nonverbal cognitive impairments than do those with more anterior–posterior symmetry (Dennis et al., 1981; Fletcher et al., 1996; Ito et al., 1977).

Because they affect the development of the midbrain and posterior cortex, the primary and secondary brain anomalies of SBH can be expected to disrupt action-based visual perception more than object identification. To date, no studies of SBH children have explicitly compared object-based and action-based visual perception. In this paper, therefore, we explored whether impairment on a range of visual perception tasks for children with SBH varies with task demands for object identification or visually guided movement, overt or covert. On the basis of task characteristics and

evidence about performance of normal and brain-injured individuals, we identified a set of tasks as requiring primarily object-based or primarily action-based processing (the latter including tests of the representation of visual space in egocentric coordinates, and the coupling of these coordinates to movement). We compared children with SBH to age peers by calculating effect sizes that measured the magnitude of the differences between SBH children and their age and geographically matched controls. Our two hypotheses were the following:

1. Children with SBH would perform more poorly than controls on object-based than on action-based visual perception tasks, because the primary and secondary brain anomalies of SBH affect the midbrain and parietal cortex.
2. Within action-based tasks, there are two different predictions. If the documented upper-limb motor deficits (mediated by cerebellar dysmorphology) of children with SBH drive their poor visuomotor integration, then they will perform more poorly relative to controls on tasks requiring visual perception linked to overt action (tracking, drawing, avoiding obstacles) than on tasks requiring multistable representations of visual space and covert action (depth perception, figure–ground relations, mental rotations). Alternatively, if the bilateral posterior cortical impairments of SBH are central, then the reverse pattern of performance will hold within action-based tasks.

METHODS

Research Participants

Participants were 6- to 17-year-old children with SBH from two sites, Houston and Toronto, each with an IQ score at or above 70 on at least one of the Wechsler or Binet intelligence scales. Spina bifida had been diagnosed at birth, and hydrocephalus diagnosed at this time or shortly thereafter and treated by a diversionary shunt. The children are typical of children with SBH without mental deficiency. Control children were of the same age and from the same educational system as the SBH group, and had been selected by teachers to have average classroom performance in language arts and reading. Gender composition was similar in the SBH and control groups.

Tasks

Object-based visual perception tasks

Visual illusions (Visual Illusions Test; Dennis et al., 2001). Children viewed visual illusions presented on 20 × 25 cm cards, with unlimited exposure time. The cards pictured illusory distortions of size, area, and length, such as the Müller-Lyer illusion, size contrast illusions and the Wundt area illusion. Children were required to indicate what they

saw; for example, in the Müller-Lyer illusion in which two shafts are equal in length but the lower one appears shorter, they indicated whether the two horizontal lines appeared the same or different lengths. The score was the number of correct identifications (15).

Illusions of size, length, and area are based on relative judgments of constancy scaling that enhance the local coherence of object perception, which likely involves ventral occipital–temporal lobe functions (Farah, 1995). Further, illusions of length are spared after brain lesions that disrupt the dorsal visual system (Vallar et al., 2000).

Face recognition (Benton Face Recognition Test; Benton et al., 1983). Children identified and discriminated photographs of unfamiliar faces by matching identical front-view photographs, front-view to three-quarter view photographs, and front-view photographs under various luminance conditions. The score was the number of correct identifications (27).

Neurophysiology and clinical data support the view that face information is an object-based, ventral stream process (Haxby et al., 1991; Tovée & Cohen-Tovée, 1993). Cells in the inferior temporal cortex and the superior temporal sulcus discharge selectively to faces (Desimone, 1991; Perret et al., 1987). Different face recognition operations activate different neural circuits; for example, the inferior temporal cortex responds to single exemplars and the superior temporal sulcus responds to facial expressions (Andreason et al., 1996). Face recognition deficits occur most frequently after infarcts in the posterior cerebral artery that supplies the inferior longitudinal fasciculus and the medial cortex of the occipital and temporal lobes (DeRenzi, 2000). In a review of 99 published cases of object agnosia, nearly all those with face recognition deficits had temporal or temporal–occipital lesions (Farah, 1995).

Object identification (Gollin Figures; Gollin, 1960). In this visual closure task, children were required to identify 20 familiar figures, each presented in 5 degrees of fragmentation. The score was the number of guesses required to identify the 20 objects (100). The higher the score, the poorer the object identification.

Inability to obtain visual closure on fragmented pictures of common objects is a classical test for object agnosia (Farah, 1995). Individuals with ventral, occipitotemporal lesions fail such tasks.

Line orientation (Judgment of Line Orientation (JLO); Lindgren & Benton, 1980). In this task, children were required to estimate angular relations between line segments by visually matching angled line pairs to 11 numbered radii forming a semicircle. They identified which two lines were in exactly the same position and pointed in the same direction as the two stimulus lines. The score was the number of correct judgments (30).

Orientation is part of the object identification system (Livingstone & Hubel, 1988). Clinically, posterior brain lesions

are associated with defective performance on the JLO task (Benton et al., 1975), but it is not clear whether posterior lesions included both ventral and dorsal lesions. More recent regional cerebral blood flow studies suggest that the JLO task activates the occipitotemporal cortex (Hannay et al., 1987), probably because, as these authors suggest, most of the test items can be solved as shape discriminations.

Action-based visual perception tasks

Stereopsis (Randot® Stereoacuity Test; Birch, 1999). In this task, children detected pictures in depth by viewing a series of 18 binocularly disparate random dot patterns through polarizing glasses. They were required to name what they saw, pretests having established that the children could name the simple objects (e.g., duck, star). Images for the right and left eyes were superimposed and stereoscopic disparities introduced in six graded steps from 800 s to 40 s of arc. Six levels of progressively finer gross disparity were tested at a 40 cm viewing distance. The score was the number of objects correctly identified over the six disparity levels (18).

The magnocellular system is important for stereoacuity and stereoscopic depth perception (Livingstone & Hubel, 1988). Cells in visual area 2 and in area MT are tuned to retinal disparity, and the magnocellular pathway passes into the parietal lobe through cortical area V1 and then through areas MT and MST to area 7a, and is important for depth and motion.

Egocentric mental rotation (Money Road Map Test; Money et al., 1965). Children imagined they were walking through a city. They traced a path with a series of 90° turns and decided, at each turn, whether they would turn to their right or to their left to continue the walk. The 32 turns required either no rotation, a half rotation following no rotation, a half rotation following a full rotation, or a full rotation. The score was the total number of correct turns (32).

Mental rotations on the level of imagery depend on the integrity of the parietal lobe (Butters et al., 1970). Imaging studies show that mental rotation of visual stimuli produces robust activation of parietal regions (Alivisatos & Petrides, 1997; Cohen et al., 1996), and, further, that greater angular disparities and error rates are associated with more activation in superior parietal regions (Carpenter et al., 1999; Tagaris et al., 1997). Mental rotations that also involve spatial working memory are associated with frontal lobe activation. The Money Road Map Test (Money et al., 1965) requires no spatial working memory, because the required mental rotations remain in view of the participant through the task. For the Money Road Map Test, parietal brain lesions produce a greater number of total errors than do frontal lesions, especially on turns requiring mental rotation (Vingerhoets et al., 1996).

Visual multistability (Multistable Figures; Dennis et al., 2001). Children viewed visual illusions presented on 20 × 25 cm cards, with unlimited exposure time. The cards showed

multistable figures, which included figure–ground reversing stimuli, fictions (illusory contours or surfaces), perspective reversing figures (“magic” staircase), and paradoxical (impossible) figures. For example, in one figure–ground reversing stimulus, two animal heads were perceived to alternate with a telephone, and children were asked to say what they saw and then to say if they saw anything else. The score was the number of correct identifications (10).

Multistability in perception involves a top-down modulation of visual cortex by frontal-parietal brain regions which are important for the multistability in perception, but not for perception as such (Lumer & Rees, 1999; Lumer et al., 1998). Perception of multistable figures is part of a more general purpose dorsal stream mechanism that also mediates exploratory eye movements (Leopold & Logothetis, 1999).

Visual figure–ground (Visual Figure–Ground; Gardner, 1988). Children found a form conglomerated in a ground of lines and contours. The task requires conscious effort to extract an embedded form from hatching and other irrelevant contours. The score was the number of correct identifications (16).

Neurophysiological studies, as well as studies of neurologically-intact and neurologically compromised individuals suggest that the definition of perceptual boundaries is a magnocellular function (Livingstone & Hubel, 1988). Initial segregation of figure from ground occurs at V1, but explicit identification of contour appears to be associated with the magnocellular geniculate subdivision. Perceptual experiments on neurologically intact individuals designed on the basis of the features of the magnocellular system from single-unit studies involve tasks of luminance contrast, linking by colinearity or illusory borders, contour, perception of depth from perspective, relative movement, and figure–ground discrimination (actually, what the Gestalt psychologists of the 1920s and 1930s used to define figure–ground perception, Livingstone & Hubel, 1988). Clinical deficits of individuals with bilateral parietal lesions include poor depth perception, difficulties using information about contours, confusion about whether objects are in front of the ground, difficulties detecting multiple objects when they are adjacent or overlapping, attention to local but not global detail, and distorted figure–ground perception (Rafal, 1997, 2000).

Visual pursuit (Rod Slide Test; McCarron, 1976). This task requires smooth visual tracking across space. Children performed a controlled, nonballistic movement (sliding a bead on a rod along a horizontal plane as slowly as possible). The score (including both hands) involves the time to move the bead the full distance between the end posts, as well as impulsive jerky movements, head and body shift, or extraneous movements. The score is adjusted into scaled scores by age norms.

Neurons in the primate parietal cortex are involved in the smooth visual tracking required for shifting spatial atten-

tion (Anderson, 1989; Maunsell, 1995); shifts of spatial attention between locations activate regions in the superior parietal cortex (Peterson & Gibson, 1994). Parietal lesions impair visual control of action (Milner & Goodale, 1995), such as reaching to targets under visual guidance (Perenin & Vignetto, 1988).

Drawing (Developmental Test of Visual–Motor Integration; Beery, 1982). This task required the appreciation of spatial organization and the production of visually guided motor responses. Children drew increasingly more difficult visual patterns using pencil and paper. The score was the number of correct drawing elements (50).

Visually guided actions involve the path from the primary visual cortex to the parietal lobe (Maunsell et al., 1990). Drawing difficulties are part of the clinical spectrum of parietal lobe pathology (Critchley, 1953), and occur frequently with parietal lesions (Diller et al., 1974; Garron & Chelfetz, 1965; Mendez, 2000).

Route finding (WISC Mazes; Wechsler, 1949). Children drew paths through a series of mazes of increasing complexity, defined by the number of blind alleys. The score for this timed task was based on success in completing the maze while avoiding blind alleys (45).

Adults with parietal lesions are most impaired (more than frontal lesions) on tasks of visual or tactile route finding (Semmes et al., 1963; Teuber, 1964).

Route planning (Porteus Mazes; Porteus, 1965). Children planned paths through a series of mazes of increasing complexity, defined by the number of blind alleys. The task is untimed, and must be done by planning rather than trial and error. If an error is made, the maze is removed and a fresh maze presented. Score is the test age (in decimal years).

Procedures

The data from each task were used to calculate an effect size (ES) to provide a common metric across tasks qualifying how much the SBH and control groups differed. The ES statistic, d (Cohen, 1977), is the difference between the means for the group of interest and a control group in standard score form, namely, the ratio of the difference between the means to the population standard deviation. 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 would influence results of traditional parametric statistical tests.

The visual perception data were collected over several years during several peer-reviewed grant cycles. The Houston sample consists of one SBH cohort and one control cohort, tested at the same time on the following tests: Face Recognition, Judgment of Line Orientation, Visual Figure–Ground, and Developmental Test of Visual–Motor Integration. There were three Toronto samples, each consisting of a SBH cohort and a control cohort. The first Toronto SBH

and control cohorts were given the Gollin Figures, Money Road Map Test, WISC Mazes, Porteus Mazes, and (SBH alone) Rod Slide Test. The second Toronto SBH and control cohorts were given the Visual Illusions and Multistable Figures. The third Toronto SBH and control cohorts were given the Randot® Stereoacuity Test. There was no overlap between individuals in the first and second Toronto samples; there was 20% overlap between individuals in the second and third Toronto SBH groups. For purposes of calculating effect sizes, comparisons were made between SBH and control children from the same site tested at the same time.

RESULTS

Descriptive statistics and group comparisons for each of the 12 tasks are presented in Table 1. The data from each task were used to calculate effect sizes (ES), which are illustrated with 95% confidence intervals in Figure 1.

Although effect size computations are independent of sample sizes, estimates based on smaller samples are more variable, that is, they are estimated with less precision and thus would vary more from experiment to experiment conducted under the same sampling conditions. We addressed this issue by reporting confidence intervals for the effect size estimates, which will be wider for effect sizes based on smaller samples, all other things being equal. The variance estimate that goes into the denominator of the effect size estimate is not an estimate of the population variance in the mean, but an estimate of the population variance in the measure. This variance estimate, if estimated correctly, is an unbiased estimate of the population variance in the mea-

sure, regardless of the sample size (provided n is at least 2). Thus, although the estimate will be more precise in larger samples, it is not “less biased” because it is unbiased at all sample sizes.

The data provide confirmation of the first hypothesis. The effect sizes are large for action-based tasks ($M ES = 1.03$) and small to moderate for object-based tasks ($M ES = .48$). For the second hypothesis, visual multistability and overt action on visual information are both significant action-based deficits in children with SBH. Effect sizes were slightly greater for tasks requiring multistable representations of visual space, such as depth perception, figure-ground relations, and mental rotations ($M ES = 1.14$), than for tasks of visually guided overt action, such as tracking, drawing, and avoiding obstacles ($M ES = .92$). However, effect sizes for both tasks are large, suggesting that both the cerebellar mediated upper limb motor deficits and the posterior cortical deficits contribute to performance on action-based tasks. Task requirements may draw more on one system than another, but the ES for the tasks used here suggest comparable levels of impairment.

DISCUSSION

Children with SBH perform poorly on a range of visual perception tasks, in keeping with previous reports. The three new pieces of information added in this study are that children with SBH and no significant intellectual impairments: perform as well as age-matched controls on some visual perception tasks, such as face recognition; perform relatively better on tasks requiring ventral stream visual processing than on tasks requiring dorsal stream visual pro-

Table 1. Means, standard deviations, and t -test results for object-based, action-based (egocentric), and action-based (movement) visual perceptual tasks for children with spina bifida/hydrocephalus and controls

Visual perception tasks	Spina bifida			Controls			Comparison
	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	
Object-based							
Visual Illusions [T]	7.0	2.1	32	7.3	2.4	32	$t(62) = 0.4, p = .6974$
Face Recognition [H]	18.9	3.7	27	20.1	3.2	18	$t(43) = 1.1, p = .2591$
Object Identification [T]	46.2	7.8	23	40.6	8.8	23	$t(44) = 2.3, p = .0263$
Line Orientation [H]	11.6	8.7	48	17.8	8.5	21	$t(67) = 2.8, p = .0075$
Action-based–egocentric							
Stereopsis [T]	8.1	7.1	24	16.5	2.6	11	$t(33) = 3.7, p = .0007$
Mental Rotation [T]	17.3	4.5	23	20.4	6.8	22	$t(43) = 1.8, p = .0721$
Visual MultiStability [T]	4.1	2.4	32	6.3	1.8	32	$t(62) = 4.2, p < .0001$
Visual Figure-Ground [H]	7.6	4.2	33	13.1	2.3	18	$t(49) = 5.1, p < .0001$
Action-based–movement							
Visual Pursuit [T]	6.9	4.6	17	<i>10</i>	3.0	80	$t(16) = 2.8, p = .0140$
Drawing [H]	10.0	3.7	49	13.2	3.1	21	$t(68) = 3.5, p = .0009$
Route Finding [T]	24.0	14.4	23	35.6	11.4	23	$t(44) = 3.0, p = .0040$
Route Planning [T]	9.1	3.6	20	12.2	3.5	23	$t(41) = 2.9, p = .0060$

Note. T = Toronto data, H = Houston data. Figures in italics are published average scores for comparable age group.

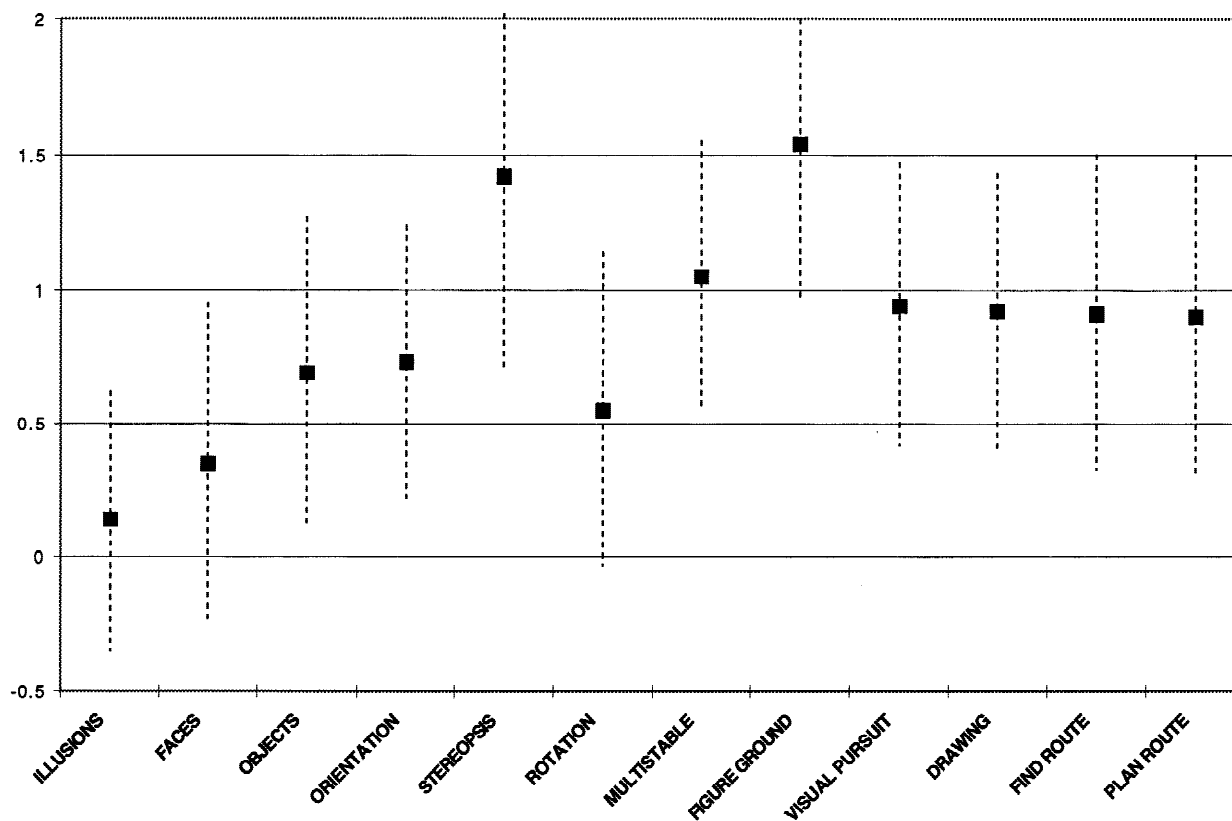


Fig. 1. Effect sizes for object identification, multistable representations of visual space, and visually guided movement. Square boxes show effect size, dotted lines show confidence limits.

cessing; and perform comparably on tasks requiring multistable representations of visual space or visually guided action.

For this study, visual perception tasks were deemed to require primarily ventral or primarily dorsal visual processing. The fit of task to process is more direct in some instances (e.g., the association of stereopsis with magnocellular, dorsal stream processing) than in others (line orientation and mental rotation tasks can be solved by a range of solution strategies). Ventral–dorsal task categorization of this kind, nevertheless, has been validated by factor analytic studies in brain-intact adults (Chen et al., 2000).

In agreement with the first hypothesis, children with SBH perform object-based visual perception tasks better than action-based perception visual tasks. They do especially well on object-based tasks, such as those, like face recognition, that are somewhat modular (Nachson, 1995). In this regard, the language of children with SBH is superficially fluent, but includes stereotypes and encapsulated phrases that make it poorly linked to its context (Dennis et al., 1987, 1994). Further, children with SBH understand idioms whose meaning is frozen, although not novel idioms, the meaning of which must be generated by linking knowledge to context (Barnes & Dennis, 1996). The encapsulated, gestalt quality of faces may simplify visual processing for

children with SBH, just as encapsulation facilitates their processing of language.

The dorsal visual system is concerned with real time modular control elicited by (and against) a changing and multistable visual world, not by any explicit reality in that world. In this sense, dorsal tasks involve the application of procedures for acting on the visual world (Bertenthal, 1996). Actions become better coordinated with visual perception as a function of neural development and experience (Bertenthal, 1996; Thelen, 1995). In infants with SBH, neural and physical limitations further limit experiences in acting on the visual world. Certainly, by preschool ages, children with SBH show the same pattern of poorer non-verbal than verbal intelligence as do school-aged SBH children (Spain, 1974), and they continue to show both motor (Hetherington & Dennis, 1999) and visual perception deficits (e.g., Fletcher et al., 1995) through the school age years.

The fact that action-based visual processing appears to be more affected than ventral processing in SBH may not be unique to this particular neurodevelopmental disorder. Children with Williams syndrome (WS) have poor visual perception on tasks of drawing, orientation, construction, and spatial transformation, but are able to perform form and face perception tasks (Bellugi et al., 1988). Some features of WS neuropathology are different from those of children with SBH,

although others are similar (e.g., poorer posterior than anterior cortex development; Jernigan et al., 1993). An explicit comparison of SBH and WS children on the same visual perception tasks would be of considerable interest.

Motor deficits are an important feature of the SBH cognitive profile. Although action-based tasks with overt visuomotor control yielded large effect sizes, children with SBH were comparably impaired on motor-free tasks requiring multistable representations of visual space. Of those tasks, three (stereopsis, figural multistability, figure-ground perception) produced a high level of impairment, and one (mental rotations) produced a moderate level of impairment. That children with SBH might have as much difficulty representing the multistable nature of visual space than acting on it is consistent with the finding that motor-free visual perception tasks are at least as challenging for children with hydrocephalus as tasks with significant motor demands (Fletcher et al., 1995). The difficulties observed in earlier studies of visual perception in children with SBH (e.g., Sand et al., 1973) cannot be attributed solely to task demands for motoric responses.

Mental rotations may be important for tasks involving mirror images (Corballis, 1982) but are not required for all rotation tasks (Corballis, 1988a, 1988b). Children with SBH had relatively moderate deficits on the test of egocentric mental rotation, the Money task (Money et al., 1965), which can be solved by different strategies, only one of which involves explicit mental rotation whereby the direction of the turn is analysed based on one's own position (Schultz, 1991). The Money task may be facilitated for SBH children because it requires only left-right responses, which may allow them to treat it as an object-centered representation (i.e., one in which locations of parts are specified with respect to a frame of reference intrinsic to the object, including left and right).

Children with SBH are challenged by visual perception tasks that require specific dorsal visual input, such as stereopsis. Stereoacuity deficits are not surprising in light of some of the primary and secondary brain effects of SBH. These include deformities of the tectal plate, which are associated with deficits in convergence and binocular fusion (Lennerstrand et al., 1990), and pressure on the cranial nerves and widening of the ventricles coincident with episodes of acute intracranial pressure, which may impair the oculomotor and vergence control centers in the upper brain stem (Leigh & Zee, 1983; Lennerstrand et al., 1990). Eye movement and depth perception disorders may also contribute to higher-level visual impairments, because eye movements are important for the retention of visual information across a saccade and for high-level scene perception (Henderson & Hollingworth, 1999). Deficits in the magnocellular pathway might also contribute to impaired visuomotor control. For instance, it is known that 3-D object-based visual representations are required to control action (Castiello, 1999), so deficient depth perception would exacerbate deficits on tasks such as drawing or making compensatory adjustments during visual tracking.

Two striking visual perception deficits in children with SBH were those involving figure-ground identification and perceptual multistability, neither of which required overt action, but both of which required the ability to represent topographical space. Poor spatial representation is a cardinal feature of Balint syndrome, a constellation of impairments associated with adult bilateral parietal lesions that include inability to perceive more than one object at a time, poor depth perception and figure-ground identification, visual disorientation, and optic ataxia (Rafal, 1997). Like adults with Balint syndrome, children with SBH appear to have poor topographical or situation models of visual space.

Effective cognitive function involves mental models of actual or imagined situations. In visual space, this might involve a model of the visual environment and one's place in it so as to track multiple or moving visual targets; in language, it might involve making inferences about the situation described in a text (Graesser & Bower, 1990). Bodily experiences affect comprehension and discourse (Roth, 1999), and children with SBH have physical and brain problems that would limit the building of situation models; for example, only children with SBH who have good visual spatial skills can represent traveled routes in two dimensions (Simms, 1987). In all, children with SBH appear to have significant difficulty building a situation model of space.

The visual perception and language deficits of children with SBH may both involve failure to create situation models. Older views of language comprehension were constituted as if the goal of language was to understand information in order to store it in memory; newer views emphasize the goal of understanding as preparing for situated action (Barsalou, 1999), and studies in this framework have shown that affordances derived from indexing words to background information may facilitate comprehension (Glenberg & Robertson, 1999). For children with SBH, deficiencies in inferential language comprehension (Barnes & Dennis, 1992, 1996) and problems in situated action may be related. In this context, it is of interest that SBH children's performance on figure-ground tasks decreases as the number of their irrelevant utterances increases (Culatta, 1980).

For children with SBH, the neuropathological basis of the observed visual perception deficits remains to be elucidated. While deficits in the cerebellum, midbrain and tectum, corpus callosum, and posterior cortex may separately and conjointly contribute to spatial deficits, the role of these particular dysmorphologies in producing poor visual perception requires the integration of neuroimaging and functional measures.

Whether the extent of parietal lobe thinning proves to be related to the degree of deficit on tasks requiring the multistable representation of space is as yet unknown. That such a relation might exist is suggested by (1) animal studies showing that the parietal cortex anticipates the retinal consequences of eye movements and updates the retinal coordinates of remembered stimuli to generate a continuously accurate representation of visual space (Duhamel et al., 1992); (2) studies linking posterior cortical thinning to poor

visual perception in children with SBH (Dennis et al., 1981; Fletcher et al., 1996); and (3) the present data, which suggest that representation of space is markedly impaired in adults with the bilateral parietal lobe pathology of Balint syndrome and also in children with SBH. Regardless of the precise pathophysiological correlates, multiple areas of posterior brain and cerebellum are involved in the visual perceptual deficits. Average performance on many tasks is lower in children with SBH relative to controls, but variability is often higher (see Table 1). This variability may well reflect differences in brain dysmorphology across individuals with SBH. Capturing these differences with neuroimaging measures and relating them to theoretically derived measures of visual perceptual processes is the next step in this research.

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