

Visuospatial Attention in Children

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Attention is the process by which we select stimuli in our environment for perception and action. The ability to orient to salient visual stimuli and to parse the visual world begins to emerge in the first few months of life and continues to evolve through childhood. This review addresses how visuospatial attention develops, is deployed, and can be damaged in children. In particular, we discuss orienting, lateralized attention, and global vs local processing. Advances in our basic understanding of the cognitive neuroscience of visuospatial attention are beginning to inform pediatric neurology, but much work remains to be done.

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Humans are constantly faced with more sensory information than they can possibly process. Attention refers to the collection of mechanisms that selects which of the many possible stimuli to process and act on. For organisms that actively maneuver in their environment, directing attention to the spatial location of a stimulus to be approached or avoided is of primary importance.

Visuospatial attention is not a unitary process. The **Table** outlines a taxonomy of terms used in this article to describe aspects of attention. We focus on components of visuospatial orienting and on the ability to flexibly change the focus of spatial attention. Orienting to stimuli in space involves elementary operations such as shifting, engaging, and eventually disengaging attention to and from objects at specific locations. Attentional orienting can be exogenous or endogenous. Exogenous orienting refers to the quick capture of attention by stimuli, such as the flashing lights of an ambulance. Endogenous orienting refers to the deployment of visuospatial attention based on goals and learned rules, such as orienting to the edge of the road to pull over and let an ambulance pass. Visuo-

spatial attention is typically oriented overtly in the same direction as the eyes and often the head and body. However, spatial attention can also be directed covertly to a point in space that is not aligned with the direction of eye gaze. Of the different spatial vectors along which one can direct attention, lateralized attention is particularly important. Finally, the focus of spatial attention can be flexibly adjusted narrowly when scrutinizing the details of an object or broadly when apprehending the global characteristics of the environment. The dynamic interplay of these components of spatial attention contributes to efficient interactions with our visuospatial world.

VISUOSPATIAL ORIENTING

Orienting to visual stimuli is one of the most basic ways that humans engage the environment. During the first 6 months of life, infant orienting behavior evolves as discrete neural pathways that control oculomotor activity mature. At 1 month of age infants fixate but do not easily redirect their gaze toward another stimulus, likely because connections from the basal ganglia tonically inhibit the superior colliculus.¹ By 2 months of age, infants direct attention to motion as connections between area

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Table. Important Concepts

Concept	Definition
Overt visuospatial orienting	Shift of visuospatial attention manifesting as movement of eyes and head toward an object of interest.
Covert visuospatial orienting	Shift of visuospatial attention without directing gaze toward an object of interest.
Exogenous cue	Feature of stimulus, such as light, color, or movement that draws visual attention. This is a form of bottom-up or stimulus-driven modulation of attentional systems.
Endogenous cue	Use of learned rule or prior experience to modify visual attention. This is a form of top-down or goal-driven modulation.
Cue validity	A peripheral cue at the same location as a subsequent target is considered valid, whereas a cue at a different location than the subsequent target is considered invalid.
Facilitation	The processing advantage characterized by a speeded response to a target preceded by a valid rather than an invalid cue (cue to target asynchrony is usually < 150 ms).
Inhibition of return	Phenomenon characterized by delayed response to a target preceded by a valid rather than an invalid cue (cue to target asynchrony usually > 300 ms).
Local attention	The narrow focus of attention to elements of an object; sometimes referred to as featural attention.
Global attention	The widening of the focus of attention to encompass the overall configuration of the object or scene.

MT (middle temporal; a region in the lateral temporal-occipital cortex specializing in processing motion) and the superior colliculus mature.¹

Between 3 and 6 months of age, infants develop more complex control of their orienting abilities. They follow targets smoothly and generate saccades in anticipation of the target's location as frontal eye field connections to the superior colliculus and brainstem mature.¹ The development of visual attention and control of eye movements are tightly integrated.² At 6 months of age, as the parietal lobes are being integrated into attentional networks, infants' control of saccades extends beyond retinotopic coordinates. They can generate accurate saccades even when the second saccade is directed to a remembered location.³

During this period, infants' abilities to direct attention covertly also develop. Covert attention can be measured by the influence of a peripheral cue on a behavioral response to a target. Typically in such experiments, a cue such as a brief peripheral flash of illumination precedes a target (by <150 milliseconds). If a subject responds faster to a target that appears at a cued location than to a target that is preceded by a cue at another location, one infers that attention was covertly directed to the location of the cue before the generation of the saccade. When there is a delay between the cue and the target (usually >300 milliseconds), a cue inhibits rather than facilitates a response to that location. This phenomenon is called inhibition of return and contributes to efficiency in visual search.⁴ Thus, both the facilitation effect and inhibition of return reflect an automatic unfolding of the effects of covert exogenous attention (**Figure 1**).

Facilitation effects of peripheral cues are not seen in 2-month-old infants, but are seen by 4 to 6 months and get more robust with age.⁵ Inhibition of return also develops between 3 and 6 months of age.⁶ Despite the fact that 6-month-old infants can shift their attention from one stimulus to another, the neural mediation of these abilities differs from adults. Immediately before adults generate saccades, a positive event-related potential occurs over parietal leads. Infants aged 6 months show a presaccadic potential over frontal leads.⁷ At 12 months of age, small presaccadic potentials emerge over parietal leads. This shift in neural

involvement from early frontal to later parietal involvement may reflect the development of orienting skills.¹ The frontal cortex may be necessary as the infants learn to plan and execute eye movements. Once the skill has been acquired, the parietal lobe mediates saccade planning automatically. The components of visual orienting, present in the first year of life, continue to improve in efficiency through childhood.⁸

Visuospatial attention is yoked to intentional, or goal-directed, motor systems.⁹ In addition to being linked to eye movements, attention also interacts with other motor systems such as those directing limb movements and ambulation, albeit in a more complex way.⁹ Thus, early motor deficits might inhibit the development of attentional systems. Children with spastic diplegia resulting from bilateral frontal perinatal brain injury associated with prematurity have impaired visual orienting,¹⁰ and healthy ambulatory children have better visuospatial skills than age-matched peers who are not walking.¹¹ Additionally, preterm infants have better-developed visual attention than children of comparable conceptional age (but younger chronologic age), presumably because they have had more interactions with their environment.¹²

Details of how motor development interacts with maturation of spatial attention remain to be clarified. Infants who move by creeping on hands and knees perform as well as ambulatory infants on visual search tasks while infants who crawl on their belly, which is more effortful than walking or creeping, perform like prelocomotor infants.¹¹ Additionally, children with diplegic cerebral palsy associated with posterior lesions do not show the same impaired visual orienting as children with anterior lesions.¹⁰ Impaired mobility contributes to, but is likely not the only factor influencing the development of, visual attention.

In adults, lesions of the parietal lobe and parts of the inferior and middle frontal gyri have been implicated in impairment of covert attention and the ability to adequately disengage from a location to which attention is directed.¹³⁻¹⁵ Children with strokes to the parietal cortex and perhaps to the inferior and middle frontal gyri show deficits in disengaging attention.¹⁶ Similar deficits may also be present in developmental disorders with struc-

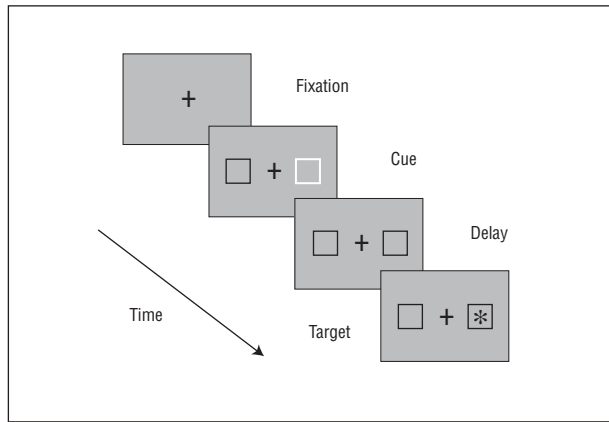


Figure 1. Typical cueing paradigm showing example of facilitation. Subject looks at fixation. Cue (highlighted box) appears on 1 side, followed by a target (asterisk). A valid cue appears on the same side as the target and an invalid cue appears on the side opposite the target. When the delay between cue and target is short (<150 milliseconds) a valid cue speeds the response. A longer delay (>300 milliseconds) with a valid cue inhibits the response.

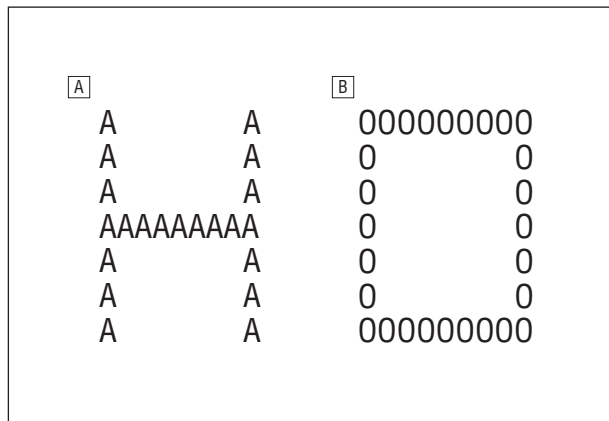


Figure 2. Examples of hierarchical figures. A, A large letter *H* is composed of individual letter *A*'s. B, A rectangle is composed of smaller ovals.

tural changes in the parietal lobe, such as children with chromosome 22q11.2 deletion.¹⁷

LATERALIZED ATTENTION

Awareness of stimuli to the left and the right is of special importance in directing spatial attention. In adults, unilateral spatial neglect has a profound effect on the functional recovery of patients.⁹ In neglect, patients fail to orient toward or respond to stimuli in space contralateral to their lesions. The syndrome is more common with right hemisphere damage and can be produced by lesions within a widely distributed attentional network, including the posterior parietal, dorsolateral prefrontal, and medial frontal cortices, as well as the thalamus and basal ganglia.

The literature on spatial neglect in children is sparse.^{18,19} Similar to adults, neglect can occur following lesions within distributed networks. In addition to lesions involving cortical structures, neglect in children occurs after injury to the basal ganglia, internal capsule,¹⁸ thalamus,²⁰ and cerebellum.²¹ It is less clear if neglect in

children is more common and more severe following right than left brain damage.

Most healthy young adults show a slight leftward bias when bisecting lines. However, this bias is not present in early childhood. Rather, children aged 4 to 5 years exhibit a rightward bias with the right hand and a leftward bias with the left hand. Only by age 7 to 8 years do children exhibit the slight leftward bias with either hand.²²

In children, subtle lateralized biases in attention following brain damage may be remarkably persistent. Young children with perinatal injury to either hemisphere preferentially remove toys from ipsilesional space.²³ Bilateral frontal perinatal brain injury can produce a lateralized deficit of visual attention, with the greatest impairment in the right visual field.¹⁰ Therefore, both hemispheres may be critical in the development of visuospatial attention before the typical adult pattern of right hemisphere dominance emerges.

Impairment of lateralized attention is also a component of developmental disorders not associated with focal brain injury. Children with developmental dyslexia and attention-deficit/hyperactivity disorder may show evidence of subtle left-sided neglect,^{24,25} which in attention-deficit/hyperactivity disorder can be normalized with treatment with methylphenidate.²⁶ Functional polymorphisms of the dopamine transporter gene *DAT1* are associated with biases in lateralized attention and may eventually contribute to our understanding of lateralized attentional deficits in developmental disorders.²⁷

LOCAL AND GLOBAL PROCESSING

Visuospatial attention is often described metaphorically as a *spotlight*. The ability to vary the size of this spotlight is important given the need to focus narrowly when scrutinizing details and widely when surveying a scene. Infants aged 4 months are sensitive to local but not global features in complex forms. Infants aged 7 months begin to respond to the whole object, an effect that becomes more robust by 10 months of age.²⁸ Infants as young as 4 to 10 months show left visual field advantages (presumably reflecting right hemisphere dominance) for overall spatial configurations and right visual field advantages (presumably reflecting left hemisphere dominance) for feature analysis.²⁹ While preschoolers are sensitive to parts as well as the whole, the ability to simultaneously appreciate and integrate both kinds of information gradually improves with age.³⁰

The protracted development of local and global attention contributes to individual differences in adolescence. In a functional magnetic resonance imaging study of children aged 12 to 14 years, children with slower behavioral responses to hierarchical figures (**Figure 2**) showed an immature pattern of bilateral activation for both global and local tasks while children with faster performance demonstrated an adultlike pattern of activity, with right greater than left activity during global analysis and the opposite pattern during local-level processing.³¹

In adults, right posterior temporal injury impairs global-level processing while left posterior temporal injury impairs local-level processing.^{29,32} Similar to adults, children aged 5 to 12 years with right hemisphere injury are inaccurate in reproducing the global organization of hierarchical figures and children with early left hemisphere injury are worse in reproducing local features. However, unlike adults, children with left hemisphere injury perform worse than control subjects on both local and global processing, even though local feature reproduction is relatively more impaired.³² Thus, early left hemisphere injury may have a greater effect than right hemisphere injury on the ability to flexibly modulate the focus of attention.

Two genetic syndromes are also associated with deficits in local or global processing. Children with Down syndrome show local-level impairments³³ while children with Williams syndrome have deficits in global processing that may be attributed to parietal and occipital volume loss.³⁴

CONCLUSIONS

Spatial attention develops from infancy through childhood. The rudiments of visuospatial functioning develop in the first 3 months of life. Between 3 and 6 months of age, flexible and dynamic aspects of visuospatial attention appear and continue to develop in efficiency throughout childhood. Despite our increasing knowledge of the developmental cognitive neuroscience of visuospatial attention, several questions of particular importance to clinicians remain unanswered. We highlight 3 such questions.

First, what effect does age at the time of focal brain injury have on attentional systems? The long-term effect of perinatal injury and injury in early or late childhood is likely to be different, but the precise nature of those differences remains to be worked out. While the effects of perinatal injury on visuospatial attention have been investigated, the effects of injury acquired in later childhood have not received similar scrutiny. Second, what aspects of visuospatial attention, if any, are affected in children with diffuse disease such as genetic or metabolic developmental disorders? Studies of children with 22q11.2 deletion and Williams syndrome demonstrate that genetic conditions can be associated with focal neurologic dysfunction. A better understanding of the abnormalities of attentional systems in these children, even if not their primary deficit, would contribute considerably to an appreciation of their functional disabilities. Third, do primary attentional deficits have an effect on the development of other cognitive systems? The orderly developmental sequence of visuospatial attention presumably has adaptive advantages. Attention plays a critical role in the development of sensory-motor integration and is likely to provide important scaffolding on which other cognitive abilities like praxis and even language are constructed. The effect of deficits in specific components of spatial attention on other cognitive domains remains unexplored. Such studies promise to offer critical insight into neural plasticity and

the interfaces between cognitive domains in the developing brain.

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