Encyclopedia on Early Childhood Development

Visual Perception and Early Brain Development

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(Published online December 10, 2008)

Topic
Brain

Introduction

A significant part of our *cerebral cortex* is devoted mainly to visual processing. Vision provides information about our environment without the need for proximity involved in taste, touch and smell. Vision has an overriding importance in every aspect of our day-to day-lives.

Subject

Different brain areas, as well as different processes of perception, are responsible for particular visual functions, such as perception of movement, colour and depth. There are even specific brain regions that deal only with facial recognition or biological (i.e., non-object) movements, and others that process only object recognition. Localized brain damage affecting these regions can lead to specific disorders, such as prosopagnosia, in which the ability to recognize faces is lost, while object recognition is unaffected. Vision would therefore seem to be a good starting place for studying the functional manifestations of brain development.

Problems

It is difficult to determine whether changes in visual abilities during development are due to limitations in peripheral structures, such as the eye, lens and muscles, or whether they are due to changes within the brain. The perceptual capacities of young infants are clearly limited by immaturities in peripheral sensory systems (e.g. spatial acuity limited by the immature retina); the developing visual circuits may benefit by being protected from "information overload" caused by too many extraneous fine details.[1] However, the question remains: What is the major constraint on the development of perception?

Research Context

Visual sensitivity is poor in newborn primates and develops gradually to adult levels during the early postnatal years. Numerous studies of visual development have described this process. Generally, contrast sensitivity and acuity, measured psychophysically, are mature by 5 to 6 years in humans and by 1 year in monkeys. Behavioural measurements show sensitivity and acuity improving together, but electrophysiological measurements suggest that the contrast sensitivity of neural elements may mature considerably sooner.[2,3,4,5]

Recent Research Results

In the last decades, there have been considerable advances in our understanding of the development of vision in the early years. It has become obvious that visual function includes various aspects that begin and mature at different times and that the visual system includes several *cortical* and *subcortical areas*, each with its own role in processing specific aspects of visual information.[6] The main breakthrough has been the ability to assess different aspects of visual function, such as acuity, visual fields or visual attention, longitudinally from the neonatal period.

This has allowed us to establish the onset and maturation of each of these aspects in normal infants, providing age-dependent normative data.[7] The combined use of *neuroimaging* and *electrophysiological* techniques has further helped to elucidate the correlation between different aspects of visual function and different areas of the brain, and to suggest possible mechanisms of maturation of visual function in normal children and in those with neonatal brain lesions. Several recent studies have provided evidence that normal development of vision depends on the integrity of a complex network which includes not only optic radiations and the *primary visual cortex* but also other cortical and subcortical areas, such as the *frontal* or *temporal lobes* or the *basal ganglia*, which are known to be associated with visual attention and with other aspects of visual function.[8]

Although the anatomy of several distinct routes from the retina to the brain had already been identified at the beginning of the 20th century,[9] the functional distinction between two separate systems, defining "where" an object is located and "what" it is, is the result of pioneering studies in the 50s and 60s, looking at the effect of brain stimulation and brain lesions. In the 70s, Bronson suggested a model for human visual development, in which newborn vision is mainly controlled at a subcortical level, with the cortex starting to mature at about 2 months postnatally.[10]

The relevance of subcortical control has also been confirmed by imaging studies showing normal ability to fix and follow in infants who had extensive cortical occipital lesions.[11]

Other studies have subsequently confirmed that the cortex takes over executive control from subcortical modules and have also suggested that cortical function involves different streams processing specific aspects of visual information.[12] Each of these aspects becomes operational at different postnatal ages and interacts with subcortical circuits to form distinct modules.[13] In the 80s, a model of visual function was proposed, involving *dorsal* and *ventral streams*, two different *cortical pathways* assumed to process different visual information. While the dorsal stream is involved in localizing "where" an object is in the space, with the *parietal lobe* as the end point of this pathway, the ventral stream and temporal lobe are engaged in "what" an object is in terms of form, colour and face recognition.[14] Further support for this theory came from other studies on primates postulating that "where" and "what" responses are largely under cortical control, whereas subcortical structures are mainly engaged in "reflex" actions.[15] Other authors have suggested another model based on two anatomically distinct streams, named *parvocellular* and *magnocellular*. The two streams, morphologically distinct at ganglion cell and lateral geniculate nucleus levels, project to different parts of primary visual cortex, V1, and continue within independent cortical streams to the colour-specific area, V4, and to the motion-selective area, V5. While the parvocellular-based system is used for form and colour vision, the magnocellular system subserves movement perception and some aspects of stereoscopic vision.[16,17] More recently, Milner and Goodale[18] proposed a further version of these models, suggesting that one stream, the ventral, is used for perceptual processing, and one, the dorsal, for controlling actions.

While the ventral stream, containing specialized areas for face perception, was proposed as the "who" system, the dorsal stream, holding areas for managing eye movements, reaching and grasping, was suggested as the "how" system. In other words, one system is devoted to deciding what and who we are looking at, and the other one decides the appropriate responses and actions to be made.

In the early months of life, the visual system is still developing. From birth to complete maturity, the eye increases to three times its size at birth, and most of this growth is complete by age 3; one third of the eye's growth in diameter occurs in the first year of life. The following information gives indicators of normal visual development in young children from birth to 3 years and the relative brain functional implications.

In a **premature infant** (depending on the extent of prematurity): The eyelids may not have fully separated; the iris may not constrict or dilate; the aqueous drainage system may not be fully functional; the choroid may lack pigment; retinal blood vessels may be immature; optic nerve fibres may not be myelinized; there may still be a pupillary membrane and/or a hyaloid system. Functional implications: lack of ability to control light entering the eye; visual system is not ready to function.

At birth: The pupils are not yet able to dilate fully; the curvature of the lens is nearly spherical; the retina (especially the macula) is not fully developed; the infant is moderately farsighted and has some degree of astigmatism. Functional implications: The newborn has poor fixation ability, very limited ability to discriminate colour, limited visual fields and an estimated visual acuity of somewhere between 20/200 and 20/400; because of the mainly subcortical orienting mechanisms, there is limited orienting to single targets from birth to 3 months; there is a preference for black and white designs, especially checkerboards and designs with angles.

By 3 months: Cortical control of eye/head movements starts to make the integration for attention switching possible; ventral and dorsal stream neural systems start to contribute together to the infant's visual behaviour; ocular movements are coordinated most of the time; attraction is to both black and white and coloured (yellow and red) targets; the infant is capable of glancing at smaller targets (as small as 2.5 cm, or about 1 in.); visual attention and visual searching begin; the infant begins to associate visual stimuli with an event (e.g., the bottle and feeding).

By 5-6 months: The infant is able to look at (visually examine) an object in his/her own hands; ocular movement, although still uncoordinated at times, is smoother; the infant is visually aware of the environment ("explores" visually), and can shift gaze from near to far easily; the infant can "study" objects visually at near point and can converge the eyes to do so; can fixate at 1 m, or about 3 ft.; eye-hand coordination (reach) is usually achieved by now; the infant may be interested in watching falling objects and usually fixates on the point where the object disappears.

Between 6 and 9 months: Acuity improves rapidly (to near mature levels); the infant "explores" visually (examines objects in hands visually and watches activity in surroundings); can transfer objects from hand to hand and may be interested in geometric patterns.

Between 9 months and 1 year: The child can visually spot a small (2-3 mm) object nearby; watches faces and tries to imitate expressions; searches for hidden objects after observing the "hiding"; is visually alert to new people, objects, surroundings; can differentiate between familiar and unfamiliar people; vision motivates and monitors movement toward a desired object.

By 2 years: Myelinization of the optic nerve is completed; there is vertical (upright) orientation; all optical skills are smooth and well coordinated; acuity is 20/20 to 20/30 (normal); the child can imitate movements, match same objects by single properties (colour, shape), and point to specific pictures in a book.

At 2-5 years of age, the child's brain functions are characterized by nearly adult basic sensory processing abilities. However, further development of brain mechanisms for analyzing complex visual scenes, specific objects and faces will occur later. While basic understanding of the social world is good, further development in the ability to predict the intentions and goals of others will continue to occur.

By 3 years: Retinal tissue is mature; the child can complete a simple form board correctly (based on visual memory), do simple puzzles, draw a crude circle and put 2.5 cm (1 in.) pegs into holes.

By 5-7 years: It is known that the basic functions of early sensory areas of the cortex have completed their development; nevertheless, the functional development of brain substrates for perception of complex visual scenes takes still longer. These changes involve continuing myelinization of connections and changes in the density of synapses within the prefrontal cortex. Specifically, there is a spurt of synapse growth followed by a period of pruning around the time of puberty.

Conclusions

The contribution of peripheral system (retinal) development in the emergence of basic visual functions can only partially explain improvements in visual behaviour, indicating that brain changes are also important.

We can conclude that sensory experience from the external world can influence the way the brain wires itself up after birth; visual experience is crucial for a child's vision to develop normally—a "use it or lose it" situation; and that treatment of common childhood eye diseases should begin much earlier than standard practice dictates.

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To cite this document:

Farroni T, Menon E. Visual perception and early brain development. In: Tremblay RE, Barr RG, Peters RDeV, Boivin M, eds. *Encyclopedia on Early Childhood Development* [online]. Montreal, Quebec: Centre of Excellence for Early Childhood Development; 2008:1-6. Available at: http://www.child-encyclopedia.com/documents/Farroni-MenonANGxp.pdf. Accessed [insert date].

This article is funded by the Centre of Excellence for Early Childhood Development and the Canadian Council on Learning's Early Childhood Learning Knowledge Centre.