The Basis for Visual Development from Prenatal Through Infancy

INTRODUCTION

In 1955, I had the privilege of participating in a preschool vision study headed by Dr. Richard Apell at the Gesell Institute of Child Development. Drs. Orvin Ide, Bernard Jander, Ray Lowry, William Moscowitz, John Streff, Harold Wiener, and I joined Dr. Apell to develop an appropriate visual examination for the preschool child from ages 21 months to 5 years. The results of this study were published in the book Pre-School Vision by the American Optometric Association. In the 40 years since we started that study, research and science have provided information to extend our knowledge to the development of vision in the prenatal embryo and fetus and the postnatal infant.

THE COMPLEXITY OF VISION DEVELOPMENT

The development of vision in the child is complex. It has taken countless ages of evolution of the human race to bring vision to its present, advanced state. The development of vision passes through several phases in the fetus, the newborn infant and the growing child.

Vision is not a separate isolated function. It is profoundly integrated with the development of the total action system of the child, including posture, coordination, personality, and intelligence. Arnold Gessel has said “vision is so intimately identified with the whole child that we cannot understand its economy and its hygiene without investigating the whole child.”

The conservation of vision, particularly in the young child, goes far beyond the detection and correction of refractive error. Acuity is only one aspect of the development of vision. We need to consider other aspects: How is the development of the child's visual system related to the development of its other neurological systems? Are central and peripheral vision in balance? Do eyes team coordinately? How does visual behavior compare with general behavior?

To answer such questions, we need a more ordered knowledge of the child as a growing organism. The child's visual history begins in the dark, warm, liquid environment of the uterus. The child's patterns of visual behavior transform in an orderly sequence through the stages of development (Appendix 1).

At 18 days old, the human embryo is only about one eighth of an inch long, but the eyes are already recognizable as bulges on the developing brain. In a specimen only a few days older, the rudiments of the eyes would also be visible as optic pits—outpouchings of the open neural plate. At 4 weeks, the optic vesicle has fully invaginated and the cerebral hemispheres are already present. The retina begins to differentiate about 2 weeks later. Up to the fourth month of development of the fetus, there is a close analogy between the layers of the cortex and those of the retina. At 16 weeks, the vestibular system is operational and necessary for ocular movement development.

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The eyes can be seen ultrasonically in more than 90% of the cases at 16 through 42 weeks of gestational age. Early slow eye movements are present by 16 weeks. Rapid eye movements begin at 23 weeks and become more frequent between 24 and 35 weeks. Eye inactivity becomes more common after 36 weeks and is associated with sustained respiration movements implying a "quiet sleep" state. Increasing phases of eye inactivity late in the third trimester imply the development of inhibitory mechanisms (controls).

Eye movement is a consistent indicator of behavioral state. Observation of combined eye and breathing patterns in the newborn seem to be a sensitive predictor of the functional development of the central nervous system. A similar assessment may be possible before birth as a means of defining physiological neuromotor patterns and of recognizing abnormal developmental conditions.

STIMULATION OF THE FETUS

The prenatal activity of the pregnant mother is critically important to the development of the fetus. Pregnant mothers who participate in exercises, dancing, and various movement activities supply their fetus with stimulations to develop their vestibular and visual systems. Some mothers may have to be confined to bed rest for medical reasons, and their fetus develops in a more passive uterine environment.

However, there are additional ways of stimulating the fetus. For example, when my wife, Lorraine, was in her second trimester, we established communication with her fetus. When Lorraine felt kicking activities, I would tap on her tummy. After numerous trials, the kicking stopped as if waiting for the tap. After the tap, there was another period of kicking. Eventually, the response was one kick for one tap. The response for two taps was more difficult, but achievable. We also added music to the experience. This experiment was duplicated with our second born. Both daughters, Terry and Nita, scored in the 90th percentile on the SAT math scores. Were the communications in utero a learning experience?

One of the most fundamental differentiations is the impress of gravity on the physical and functional development of the fetus and newborn. We note the adaptations to gravity of infant monkeys compared with that of infant humans. In man, this differentiation is complicated by the upright posture which may create interferences in the development of orientation. Accordingly, there may be visual problems of orientation, even in the early history of the human embryo, which may affect spatial-temporal development.

VISION IN THE NEWBORN

The peripheral retina of the newborn human infant is well developed, but the macular area is not. In fact, in the fovea, the receptor layer is so poorly developed in the newborn that it may be barely functional. Vision in the newborn is determined largely by the peripheral regions of the retina. This could be the reason that color vision in young infants shows some of the anomalies found in adult peripheral color vision. When does the human fovea become adult in its morphology? From evidence available, there seems to be a correlation between the development of the foveal acuity and the neurological development of the child.

Vision is not in the eye; the eye is an instrument of vision. Vision is the product of the functions of the other neurological systems interacting with the eye. The foundation for these relationships is laid down during the prenatal and first years of life when the neural pathways are formed between the eyes, the brain, and the body.

THE VESTIBULO-OCULAR REFLEX

The vestibulo-ocular reflex (VOR) helps maintain a stable retinal image by generating compensatory eye movements to offset the effects of head movements. Vision is particularly dependent upon the vestibulo-ocular reflex (VOR) arc. Interaction among the three components of the VOR will determine the functioning of the visual system in later life. The interaction between the vestibular mechanism (the balance mechanism), the eyes, and the reflex response is critical. Any fault in one will affect the smooth operation of the whole.

The vestibular system is the only system fully myelinated at birth, being operational at 16 weeks in utero and fully myelinated by 6 months in utero. After birth it responds to information relayed to it from other systems, including the reflex system.
When an infant is delivered from the sheltered, warm, liquid, dark environment of its mother’s womb to the harsh, cold, lighted, polluted air of our environment, it is a shocking experience. The infant cannot understand the strong, sudden, shocking, new sensations. Its protection is a set of primitive survival reflexes designed for immediate reaction to changes in environment and needs.

**PRIMITIVE SURVIVAL REFLEXES**

Primitive survival reflexes are automatic movements directed from the brainstem and executed without cortical involvement. They are necessary for the newborn’s survival in the first weeks of life. But they also provide essential learning experiences as foundations for future neuromuscular development and facilitate the “mapping” of neurological information in the brain. This internal mapping is a continuation of “building a visual space world” previously started in utero.6,7

These primitive survival reflexes should have a limited life-span. Their purpose is to insure the infant survives the hazardous first months of life. Then these reflexes should be inhibited or controlled by higher brain centers to permit development of higher level postural reflexes.

If the primitive survival reflexes remain active beyond 6 months postnatally, they indicate a deviation in the development of the central nervous system from continued brainstem activity interfering with the development of cortical control. The visual system development is as dependent as any other system on the transition from primitive survival to postural reflex activity. The timing of these transitions is critical.

At birth, the newborn’s vision is limited only to its immediate needs. The newborn is myopic, focusing best at approximately 8 to 10 inches from its face. The degree of myopia can vary depending on factors during pregnancy, delivery, and variables modifying development.

Primitive survival reflexes provide mechanisms to understand what the infant sees (identification) and help the infant learn to coordinate ocular systems to acquire the skills of accommodation, fusion, fixation, and convergence and to reduce excess light. Visual problems at a later age may be attributable to primitive survival reflexes remaining active beyond 6 to 12 months of age, preventing postural reflexes from developing and interfering with oculomotor functioning. Development of the visual system is dependent on neurological development. Four of the primitive reflexes influencing visual development are the Moro reflex, the tonic labyrinthine reflex (TLR), the asymmetrical tonic neck reflex (ATNR), and the symmetrical tonic neck reflex (STNR). (See Appendix 2).

**The Moro Reflex**

The Moro reflex emerges in utero at 9 to 12 weeks and should phase out at approximately 4 months after birth. It is tested by rapidly changing position of the head from the upright to a backward position (Fig 1). This triggers a reflexive extension of arms and legs outward, a rapid intake of breath, hands open as if to grasp. After a momentary freeze, the infants release their bodies and cry for help. The Moro reflex provides an immediate, automatic, involuntary “alarm” system ensuring instantaneous “arousal.”

If the Moro reflex remains active much beyond 4 months, the infant will experience acute sensitivity to changes in sound, light, touch, taste, temperature, movement, smell, flicker of fluorescent tubes, and to “blue” light of the spectrum. Continued acute sensitivity can affect biochemical and endocrine balances. Could these sensitivities be related to autistic characteristics?

![Fig 1. The Moro reflex. Reprinted with permission, from Goddard S. A Teacher’s Window Into the Child’s Mind. Eugene, OR: Fern Ridge Press; 1996.](image)
The Moro and the TLR are vestibular in origin and are activated by stimulation of labyrinths or changes of position in space.

The Tonic Labyrinthine Reflex

TLR emerges prenatally at about 16 weeks with the vestibular system and should be modified considerably by 6 weeks after birth. TLR is tested by movement of the head forward or backward beyond the upright position (Fig 2). Postnataally, the head change elicits extension of arms and legs to a near crucifixion position.

Before birth the fetus is in a liquid environment, so the effects of gravity are greatly reduced, movements and responses have been slowed, and sensory stimuli have been cushioned. After birth, control of the head against gravity is difficult. By 6 weeks, TLR begins to phase out so the infant can develop “antigravity” control of the head leading to control of balance, muscle tone and proprioception. Until antigravity control of the head is established, the infant cannot develop eye-hand control or visual acuity, balance against gravity, roll over, sit up, or bring hands to mouth.

Basically, TLR provides the mechanism for response to gravity. It should phase out rapidly in the first few weeks. If it fails to be inhibited at the correct time, it will constantly trip the vestibular in its actions and interactions with other sensory systems. A child with retained TLR may not gain gravitational security in standing, walking and moving.

Lacking a secure reference point in space (an egocentric locus), the child will have difficulty in judging space, distance, and velocity. Sense of direction is based on the knowledge of “where am I” in space and time (orientation). If the point of reference is fluctuating and unstable, the ability to discriminate up from down, left from right, or backward from forward may be erratic. Just as disoriented astronauts in gravity-free space manifest “space dyslexia,” so the child also may reverse letters and numbers, write from right to left, etc.

If the antigravity control of head and posture is limited, oculomotor functioning will be impaired because the eyes operate from the same circuit in the brain—the VOR arc. Balance will be affected by poor visual processing and vision will be affected by poor balance. This can impeded convergence and the automatic establishment of binocular vision. In therapy, we need to consider the underlying causative factors to develop integrated results.

The Asymmetrical Tonic Neck Reflex

The ATNR emerges at about 16 weeks in utero to facilitate fetal movements, develop muscle tone and provide vestibular stimulation. ATNR is tested by rotating the head to one side. This elicits the extension of limbs to the same side and flexion of the opposite limbs (Fig 3). The position of the head, rotation, and arm extension provides the first eye-hand coordination leading to vision extension from 8 to 10 inches (arm’s length) and to awareness of distance.

By 6 months of age, the ATNR should phase out. Delayed ATNR interferes with development of cross-pattern movement for crawling, walking, and balance and causes misinformation to be sent to the vestibular. Gesell and Ames, in 1947, identified the persistent ATNR as a major obstacle in establishing a preferred hand, leg, eye, or ear. It is an obstacle to crossing the midline without head movements in visual tracking during reading, handwriting, copying, and many other eye-hand activities.
The Symmetrical Tonic Neck Reflex

The STNR emerges at 6 to 8 months after birth and phases out at about 11 months. STNR comes in after the ATNR phases out, and it exerts an inhibitory effect upon the TLR.

STNR enables infants to defy gravity for the first time allowing them to raise their bodies off the floor with support of hands and knees. STNB does not permit mobility, but it does arrange for a period of "rocking" on hands and knees. This inhibits the STNR gradually, so creeping becomes possible (Fig 4).

In rocking back, the babies raise their heads up to fixate as their bottoms sink back to their ankles. When they rock forward, their bottoms raise up, arms bend and, with heads down, they fixate at near. These visual adjustments from far to near and back expand the visual development from the 8 to 10 inches at birth with the ATNR, and then to far and back to near with STNR.

If the symmetrical tonic neck reflex remains active too long, then fluent cross-pattern creeping may never be achieved. The infant may substitute a "bottom-hop" or "bearwalk" to bypass this very important phase of development.

There is a strong connection between crawling and creeping and the ability to use a written language. Veras stated, "Not only is creeping an important level of development in a child's mobility, it is terribly important in the child's visual development. In all the primitive people we have seen, the children are never allowed to creep and none of them can focus their eyes on anything closer than arm's length. We believe that when a child creeps, his near point vision is developed."9

CONCLUSION

An understanding of visual development from prenatal stages through infancy has clinical implications in visual development, not only in the infant and child, but for all ages. As functional behavioral optometrists, we are primarily clinical developmental educators concerned with "arranging conditions" to guide our patients in learning to develop their visual systems more effectively. In our search for greater insight and understanding, we have studied the development of vision in the fetus, the newborn, and the developing child. As we expand our knowledge of vision, we develop greater insight and understanding of the visual problems of our patients.

From our examinations, we find deficits such as amblyopia, strabismus, visual processing, and myopia. In most cases, our patients
have no pathology and were not born with these visual problems. Knowledge of the development of vision gives us the ability to understand and to alleviate their problems to a greater degree. Thus our patients will be able to see more, observe more, experience more, learn more, and become more efficient in everyday life.

REFERENCES


APPENDIX 1. Developmental Expecteds

<table>
<thead>
<tr>
<th>Stage</th>
<th>Developmental Characteristics</th>
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<tbody>
<tr>
<td>Prenatal*</td>
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<tr>
<td>18 days</td>
<td>Embryo 4 mm eyes visible as a bulge on developing brain.</td>
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<tr>
<td>4 wk</td>
<td>Optic vesicle fully invaginated and cerebral hemispheres present. Retina differentiates two wk later.</td>
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<tr>
<td>9–12 wk</td>
<td>Moro primitive survival reflex emerges.</td>
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<tr>
<td>16 wk</td>
<td>Vestibular system operational, necessary for eye movements. First fetal slow eye movements begin. Tonic labyrinthine reflex emerges. ATNR emerges.</td>
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<tr>
<td>24 wk</td>
<td>Vestibular system fully myelinated. Rapid eye movements beginning.</td>
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<tr>
<td>28 wk</td>
<td>Eyelids open.</td>
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<tr>
<td>Postnatalb</td>
<td></td>
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<tr>
<td>Birth</td>
<td>Vision adapted to needs within 8–10 inches. Myopic—cannot discern detail. Fovea and macula immature, undeveloped.</td>
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<tr>
<td>6 wk</td>
<td>TLR inhibition modification should occur to permit head control development.</td>
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<tr>
<td>4 months</td>
<td>Moro reflex inhibition should occur to permit adaptation to stimuli.</td>
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<tr>
<td>6 months</td>
<td>ATNR inhibition should occur to permit cross pattern movement for crossing midline, balance in crawling and walking and for establishing preferred eye, hand, leg and ear. Extension of vision to far distance.</td>
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<tr>
<td>6–8 mo</td>
<td>STNR emerges.</td>
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<tr>
<td>11 mo</td>
<td>STNR inhibition should occur to permit fluid mobility in creeping and to bring vision back from far to near distance.</td>
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<tr>
<td>12 to 30 mo</td>
<td>Fovea and macula should be adequately developed to improve visual acuity at far distance.</td>
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* Detected with ultrasound, imaging, and scanning electronic microscope.

b Detected in response to gravity.
APPENDIX 2. Primitive Survival Reflexes Influence Visual Development

Moro Reflex

Time
Emerges in utero at 9 to 12 weeks. Vestibular in origin. Phases out approximately 4 months after birth.

Test
Rapidly moving head from upright to backward elicits reflex extension of limbs outward
Hands open as if to grasp
A rapid intake of breath
After momentary freeze, releases posture and cries

Persistence
If activity persists beyond 4 months, there is acute sensitivity to sound, light, movement, touch, taste, smell and tension.
Poor pupillary response to light.

Tonic Labyrinthine Reflex (TLR)

Time
Emerges in utero at 16 weeks with vestibular system. Modified at 6 weeks after birth to permit “anti-gravity” control of head.

Test
Moving head forward or backward beyond upright elicits limb extension to near crucifixion position.

Persistence
If activity persists beyond 6 weeks after birth, there is delay in “anti-gravity” development. Interferes with roll over, sit up, eye-hand, balance, orientation, localization, convergence and binocular development.

Asymmetrical Tonic Neck Reflex (ATNR)

Time
Emerges in utero at 16 weeks.
Phases out by 6 months after birth.

Test
Rotating head to one side elicits limb extension to the same side and flexion of the opposite limbs (homolateral).

Persistence
If activity persists beyond 6 months after birth, it interferes with development of cross pattern crawling and walking, preferred hand, leg, eye and ear, visual tracking without head movements, reading and writing.

Symmetrical Tonic Neck Reflex (STNR)

Time
Emerges at 6 to 8 months after birth.
Phases out at about 11 months.

Test
Raising his body off the floor with support of hands and knees

Persistence
If activity persists beyond 11 months after birth, it interferes with fluent cross pattern creeping, expanding visual space, near point vision development and binocularity.