The Development of Sensory Systems During the Prenatal Period

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Full Text: Headnote ABSTRACT: This paper will examine the anatomy and physiology of the development of the seven senses in utero. On the basis of this knowledge clinicians will be better able to promote more peaceful as well as enriched prenatal environments and plan interventions for children at risk for later developmental difficulties. KEY WORDS: Prenatal, sensory systems, development, auditory, vision, taste, olfactory, tactile, proprioception, vestibular. INTRODUCTION There are many factors, both prenatal and postnatal, that influence a child's development. These factors include nature (genetics, epigenetics, familial tendencies, etc.) and nurture (environmental) influences. Thomson (2004) states that both embryology and fetal research support how nature and nurture overlap and cannot be easily separated. Smotherman (1995) describes how "development of human life is a process of epigenesis where life emerges from an interaction of genetic, phenotypic (including individual form, behavior, and metabolism) and environmental variables". One major factor that contributes to neonatal development is how his/her sensory system becomes integrated. Sensory integration is the process that involves organizing sensation from the body and the environment (Ayres, 1979). There are five sequential steps in the dynamic process of sensory integration, which are sensory registration, orientation and attention, interpretation, organization of a response, and the execution of a response. This paper focuses on describing how the seven senses develop in utero, so that sensory integration can take place. From this knowledge, clinicians can improve their understanding of the development of normal sensory capabilities, learn to promote enriched prenatal environments and plan interventions for children at risk for sensory integration dysfunction. The Seven Senses We have four distal senses and three proximal or hidden senses. The four distal (or foreground) senses include vision, hearing, taste, and smell. It is difficult to separate touch and join and body movement, so the tactile sense is considered part of both the proximal and distal senses. The three senses that are proximal or hidden are touch (tactile) awareness, body position (proprioception) and movement (vestibular) awareness. The proximal senses are complicated and are considered key to one's ability to integrate sensory information accurately (Schepers &Benson, 2006). For the purpose of this paper, neuro-typical is defined as children who have not been diagnosed with any disorders of speech, language, cognition, or motor development. These children are considered normal in their development, or have developed without disturbances of their neurological system. DEVELOPMENT OF FOREGROUND SENSES IN THE UNBORN CHILD Auditory The vestibule-cochlear organs (the ear) are the organs that provide hearing. Each ear has three parts-external, middle, and internal. The external ear consists of the auricle and the external acoustic meatus. The middle ear consists of air space, the tympanic cavity and the temporal bone. The internal ear is a complicated fluid-filled space called the labyrinth, which is enclosed by the temporal bone. The determination of when and how a neonate begins to hear was accomplished by using two primary methods. First, sound was transmitted through air by attaching a loud speaker to the mother's abdomen using a rubber or foam ring. The other method transmitted sound to the mother's abdomen by an oscillatory source (sound vibrator or tuning fork) placed near the fetus' head (Lecanuet, 1995). Ultrasound measured the fetus' motor responses, cardiac acceleration changes, and ontogeny of responses. By measuring the fetus' response, researchers determined when the fetus actually began functional hearing. Hearing begins during the fifth week of gestation. The baby actively hears before the first trimester is completed, but hearing continues to mature slowly after the baby is born (Larson, 2001). Between 10 to 20 weeks gestation, along with the inner and outer ear structures, about 16,000 hair cells form (Thomson, 2004). By 23 weeks gestation, the fetus responds to sound and will indicate sound preferences. A baby as early as 26 weeks gestation learns intonation, rhythm, and other speech patterns of the mother's voice. Myelination, which improves the speed of neural transmission by covering the long axonal extensions with fatty white layers of glial cells, follows a head to tail pattern (caudal to rostral) (Thomson, 2004). While myelination is on going, this process is not completed in the brain stem until birth. By 34 weeks gestation, the auditory threshold levels are similar to adult preferences. This allows the fetus to develop selective preferences for specific sounds. Using neural patterns of language, emotional context for phonological rhythms, tones and sequences of the mother's speech, the fetus typically discerns their mother's voice during the third trimester (Hartman &Zimberoff, 2002). Elliot (1999) illustrated how the fetus habituates to sound, develops a conditioned response, increases arousal levels and demonstrates interest to novel noises. Elliot also identified how the most important sound to the fetus is the mother's voice. The mother's voice brings pleasure to the fetus, so the fetus responds, and begins interacting with her voice. This researcher also noted that since the neonate hears clearly, loud noises could also induce hearing loss. Truby (1975) investigated how the mother and baby are attuned to each other by matching spectrographs. Truby also identified that by four days following birth, infants show the ability to distinguish language from other sounds and preferred their mother's voice and language. Vision Vision is a powerful sense that helps the infant develop a curiosity of his/her world. Without vision the baby cannot orient to light, faces, or objects. From this author's (SMF) clinical experience, babies who are blind often lack the internal motivation to move and explore their environment. For example, without the sight to see the toy placed just out of reach, the child is content to just stay put wherever they are placed. There is no spontaneous exploration, because everything appears black in the first place. While these babies learn to explore their world through their other senses, they miss the visual stimulation. The primary organ of vision is the eye, with the earliest organ being the eyespots, which form around 28 days gestation (Tsiaras, 2002). The eye is derived from four cellular sources, which include the neural ectoderm, the somatic ectoderm, the neural crest and the mesoderm. O'Rahilly and Muller (1996, p. 419) describe the development of the eye in great detail, using a series of animal dissections and ultrasound technology. In general, vision develops from the outside inward. The optic sulci become visible at four weeks. The retinal and lens discs appear around four and a half weeks. The lens becomes indented to form the optic cup and lens pit. The lens pit then closes to form the lens vesicle. At the end of the embryonic period, the eye is fully formed. One fascinating aspect of visual development is that the eyes initially face lateral during the embryonic period. As the fetus develops, the eyes move inward and end up about 40 mm apart facing anterior on the baby's face. In addition, the optic nerve develops from the optic vesicle. The optic nerve is really a fiber tract that connects the brain with the retina (O'Rahilly, 1996). The cranial nerve that innervates the eye is the oculomotor nerve. The oculomotor nerve supplies motor ability to the eye for visual tracking. Around two months into gestation, the axonal connections form. Between 14 and 28 weeks gestation, approximately 100 million neurons form the visual system but these are not connected until later in development. During the middle of the prenatal period, all the layers of the adult retina form. O'Rahilly &Muller (1996, p. 427) dissected cats to determine when the rods and cones were functional. During the last trimester, the fetus appears to see light through the mother's belly and the amniotic fluid. This helps refine the connections of the rods and cones in the eyes (Tsiaras, 2002). Although visual development begins in the fourth week of gestation, the vision system takes many years after birth to mature (Larson, 2001). Final myelination is not complete until middle childhood. Animal studies helped determine when vision develops in utero. O'Rahilly &Muller (1996, p. 429) discovered that fetal monkeys need all the neurons of the visual system to reach their final positions before the eyes began to work. Before visual input could be correctly interpreted, O'Rahilly &Muller also used the fetal cat to record electrical activity of retinal neurons. Similarly, the human baby (after birth) takes about two years to develop a dominant eye (when the brain ceases to accept synapses from one eye). Oculo-motor skills are important in visual development. Oculo-motor skills allow the infant's eyes to move smoothly and track objects. O'Rahilly &Muller (1996) tracked fetal eye movements during the fetal period using ultrasound. This is important to the developing fetus, as oculo-motor skills allow the baby to watch and visually track moving objects, people and light. At birth, visual tracking is jerky. However, by three months it becomes smooth and coordinated. Taste The gustatory sense is limited to the tongue. The mouth forms from the stomatodeum, which initially creates a facial depression. The cranial section then develops into the mouth and the pharynx. The tongue, which houses the taste nerve endings, is derived from stomodeal ectoderm. Taste buds emerge on the tongue around eight weeks gestation. By 13 weeks, these buds form in the mouth and continue to innervate the brain after birth. The fetus tastes the amniotic fluid during the fourth month. The amniotic fluid biases the fetus for future taste preferences (Hill, 2001). Additionally, the fifth and ninth cranial nerves, trigeminal and glosso-pharyngeal nerves, provide general sensory innervations to the tongue. Olfactory The early nasal structures form between six to eight weeks. There are generally four distinct systems that comprise smell. These include the main olfactory, the trigeminal, the vomero-nasal, and the terminal. For the purposes of this paper, we shall focus primarily on the main olfactory system. The main olfactory system is composed of olfactory epithelium, which is located at the apical part of each nasal cavity. The main olfactory system is linked by the olfactory nerve to the primary olfactory center and into the diencephalic centers for processing (Schaal, 1995). This system rapidly develops by sending nerve fibers from the outside surface of the embryo into deeper regions of the brain. The nostrils form around seven weeks (Larson, 2001). During the 13th week the olfactory bulbs separate from the nasal cavity and the facial bones. The olfactory sense is almost fully mature at the end of the embryonic stage. By the end of the first trimester, the main olfactory subsystem is anatomically mature and can carry out sensory performance. Researching the anatomical formation of the olfactory system was much easier to accomplish than determining when it is fully functioning. How, when and what a human fetus smells is currently not obtainable through modern research methods. Researchers have used animal models to discover what the unborn animal can smell. For example, Schall, Orgeur, and Rognon (1995, p. 220) describe how the sheep (ovine) fetus were externalized from the uterus and amnion and implanted with intranasal catheters and electrodes. The fetus' nose was then injected with two different smells-lemon and a foul odor. The foul odor increased the heart rate more than the lemon smell. Tsiaras (2002) believes that early olfactory preferences reflect the prenatal experience. Smell is critical to survival because the baby needs to identify his/her mother for survival and food. However, smell does appear to fully function during the last trimester. Acquisition of the neonatal odor preferences is observed shortly after birth. Schaal, Orgeur, and Rognon (1995) exposed babies who were born prematurely to odors and observed oral, facial, and general motor activity. Babies born at term were exposed to bad odors (described as "oil of asa fetida") and an unspecified floral odor. Full term babies were tested between one hour and five days old, while the preterm babies were exposed between twenty hours to five days. Both full term and preterm babies responded to both the floral and unpleasant odors, however full term babies were better able to detect the smell when it was placed under the nostril at a lower concentration. This suggests that even preterm babies can smell but not as well as a full term baby. Although this research used a small sample (29 full term babies and 19 premature babies) and did not control for the amount of prematurity, this is one of the first research studies to explore the development of human smell. DEVELOPMENT OF THE BACKGROUND SENSES Tactile The tactile system (the sense of touch and pressure) is the earliest system to develop in utero. It is also the most mature sensory system at birth (Kandel, 2000). Within three weeks following conception, the tactile system begins to emerge. By five weeks, the embryo can sense pressure to its lips and nose. At nine weeks, the embryo's arms, chin, and eyelids also sense pressure. By ten weeks, the legs sense pressure. Amazingly the last area of the body to develop a sense of tactile awareness is the back and the top of head, which does not develop until shortly after birth. This apparently helps decrease the perception of pain during labor and delivery (Elliot, 1999). The skin is the primary organ that perceives pressure. Nerve receptors for tactile awareness are imbedded in the skin. The skin also serves as the barrier between the body and the outside environment. During the late embryo and early fetal period, the skin on the palms, soles, and digits is formed. The ridges between the digits appear on the hand as early as 12 weeks (O'Rahilly &Muller, 1996, p. 151). The tactile system has two major purposes, namely to provide protection and discrimination of input. According to Anand &Hickey (1987), pain perception appears intact after the seventh week of gestation. The early origin of pain perception appears in the brain and spinal column at 12 to 16 weeks. However the fetus appears to respond reflexively to touch around eight weeks of gestation. At 14 weeks most of the body responds to touch. Later during the fourth month of gestation, the sensory-motor map in the brainstem begins processing the sense of pressure. The tactile system also provides the baby the ability to discriminate. This ability becomes more developed over time after birth. Babies learn to distinguish deep pressure, light touch and precise location of touch through experience. This discriminative capacity is important for functional manipulation of objects (Williamson &Anzalone, 2001). Proprioception Proprioception is the body's position sense. It allows for a continuous internal awareness of body posture. Proprioceptive receptors are found in muscles, tendons, and joints. As the muscles, tendons, and joints develop, so does proprioception. Tiny nerves provide the awareness of where the body is in space, thus allowing humans to coordinate movements, determine the force needed by muscles to move, and change joint angles during movement. Proprioception also tells us about the position and movement of internal organs. For example, the Pacinian corpuscles line the gastric wall and give sensory information to the brain when the stomach is "full" (Williamson &Anzalone, 2001). Proprioception is highly related to vestibular system section. Vestibular The vestibular system is located in the inner ear and helps the body respond to movement of the head and body in relation to gravity. This system contributes to the sense of balance and equilibrium as well as a sense of where the body is moving in space. This system is located in the bony labyrinth of the skull near the hearing mechanism (Williamson &Anazalone, 2001). The inner ear has three structures, which make up the vestibular system. The semicircular canals record the speed and direction of movement. The saccule and utricle record the direction of gravity and linear movement. Balance and equilibrium begins to emerge at five weeks gestation (Larson, 2001). Between seven and 14 weeks, axonal fibers form the tiny hairs in the ears. These cilia support neuronal connections and provide movement information to the brain (Tsiaras, 2002). The vestibular nerve is myelinated first; however, this is a slow process and will continue into puberty. By five months gestation, the vestibular system is in place and functioning. This rapid maturity leaves the vestibular system more vulnerable to damage than the other sensory systems (Elliot, 1999). The vestibular system also is responsible for self-soothing. The vestibular system allows the neonate to recognize rocking and bouncing. If vestibular development is dysfunctional or disrupted, deficits may lead to attention and perceptual abnormalities, learning disorders and emotional problems (Elliot, 1999). In addition, the vestibular system helps an infant maintain and transition between states of alertness. It is also partially responsible for emotional regulation. Limitations of this Paper This paper limited its discussion to the development of the seven senses during the prenatal period. There was also minimal reference made to the impact of sensory integration on emotional development, self-regulation, and attachment. Further discussion on integration and sensory-motor capabilities of the neonate will be presented in a later paper. SUMMARY This paper reviewed how and when the seven senses develop. No one sense is more important than another. Each sense is integrated and interpreted by the brain to determine the type of adaptive response produced. The fifth week of gestation starts the beginning of sensory-motor capabilities. The sight, sound, smell, taste, touch, body position and vestibular organs form sending neural fibers into the brain. The sensory systems' neural development continues throughout the prenatal period and is further refined during post-natal life. Using the knowledge of how normal sensory systems develop, clinicians can promote enriched prenatal environments and plan stimulating play for children.

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