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Fetal Brain Behavior and Cognitive Development

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The human brainstem is fashioned around the 6th–7th week of gestation and matures in a caudal to rostral arc, thereby forming the medulla, pons, and midbrain. The medulla mediates arousal, breathing, heart rate, and gross movements of the body and head, and medullary functions appear prior to those of the pons, which precede those of the midbrain. Hence, by the 7th–9th gestational week the fetus displays spontaneous movements, 1 week later takes its first ''breath,'' and by the 25th week demonstrates stimulus-induced heart rate accelerations. As the pons, which is later to mature, mediates arousal, body movements, and vestibular and vibroacoustic perception, from around the 20th to 27th weeks the fetus responds with arousal and body movements to vibroacoustic and loud sounds delivered to the maternal abdomen. The midbrain inferior-auditory colliculus followed by the superior-visual colliculus is the last to mature and in conjunction with the lower brainstem makes fine auditory discriminations and reacts to sound with fetal heart rate (FHR) accelerations, head turning, and eye movements—around the 36th week. When aroused the fetus also reacts with reflexive movements, head turning, FHR accelerations, and may fall asleep and display rapid eye movements. Thus fetal cognitive motor activity, including auditory discrimination, orienting, the wake–sleep cycle, FHRs, and defensive reactions, appear to be under the reflexive control of the brainstem, which also appears capable of learning-related activity.

Key Words: Fetus; brainstem; motor development; emotional development; brain development; learning; cognition.

It is now well established that the human fetus is capable of some degree of behavioral complexity. In fact, as early as the 9th week of gestation the fetus is able to spontaneously move the extremities, head, and trunk (de Vries, Visser, & Prechtl, 1985). It has also been suggested that the near-term fetus may be endowed with some degree of cognitive capability (e.g., Hepper & Shahidullah, 1994; Kisilevsky, Fearson, & Muir, 1998). Cognition has been inferred based on alterations in fetal heart rate (FHR) and habituation to airborne sound (Kisilevsky & Muir, 1991), response-declines to vibroacoustic stimuli (Kisilevsky et al., 1998; Kuhlman, Burns, Depp, &

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Sabagha, 1988), and what appears to be neonatal preferences for the maternal voice as well as melodies and stories presented up to 6 weeks prior to birth (DeCasper & Fifer, 1980; DeCasper & Spence, 1986; DeCasper, Lecanuet, Busnel, Granier-Deferre, & Maugeais, 1994; Lecanuet, Granier-Deferre, & Busnel, 1989).

As is detailed below, the behavior of the fetus and newborn is likely a reflection of reflexive brainstem activities which are produced in the absence of forebrain-mediated affective or cognitive processing, i.e., thinking, reasoning, understanding, or true emotionality (Joseph, 1996a, 1999; Levene, 1993; Sroufe, 1996). It is the much-slower-to-develop forebrain which generates higher-order cognitive activity and purposeful behaviors and which is responsible for the expression and experience of true emotions including pleasure, rage, fear, and joy and the desire for social-emotional contact (Joseph, 1992, 1996a,b, 1999; MacLean, 1990). At birth and for the ensuing weeks, the forebrain is so immature that its influences are limited to signaling distress in reaction to hunger or thirst; a function of the immature hypothalamus (Joseph, 1982, 1992, 1999) in conjunction with the midbrain periaqueductal gray (e.g., Larson, Yajima, & Ko, 1994; Zhang, Davis, Bandler, & Carrive, 1994). Although various limbic nuclei become functionally mature over the course of the first several postnatal months and years (Benes, 1994; Joseph, 1992, 1999), the neocortex and lobes of the brain take well over 7, 10, and even 30 years to fully develop and myelinate (Blinkov & Glezer, 1968; Conel, 1939, 1941; Flechsig, 1901; Huttenlocher, 1990; Yakovlev & Lecours, 1967).

It is rather obvious that the neonate is able to scream and cry and can even slightly lift the corners of the mouth as if smiling. However, these do not appear to be true emotions (Sroufe, 1996; however, see Izard, 1991). In fact, smiling, as well as screaming and crying can be produced from brainstem stimulation even with complete forebrain transection or destruction (Larson et al., 1994; Zhang et al., 1994; reviewed in Joseph, 1996a). Hence, neonatal and premature infant ''smiling'' or distress reactions to noxious stimulation (e.g. heel lance) are also likely brainstem mediated, particularly in that they may be triggered in the absence of any obvious stimulus source and following forebrain destruction or lack of development (anencephaly). However, as brainstem maturation continues in a caudal–rostral arc (Debakan, 1970; Langworthy, 1937), at term and over the following weeks and months, the immature hypothalamus (which sits atop the midbrain), and thus the forebrain, increasingly contributes to and gains control over these behaviors.

The progression in behavioral complexity that begins with spontaneous fetal movements and which culminates with presumed preferences for the sound of mother's voice also appear to reflect maturational events taking place in the brainstem followed by forebrain structures. Indeed, the brainstem is first fashioned around the 33rd day of gestation (Bayer, 1995; Marin-