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Emergence and retention of learning in early fetal development

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ABSTRACT

Prior research has demonstrated that the late-term fetus is capable of learning and then remembering a passage of speech for several days, but there are no data to describe the earliest emergence of learning a passage of speech, and thus, how long that learning could be remembered before birth. This study investigated these questions. Pregnant women began reciting or speaking a passage out loud (either Rhyme A or Rhyme B) when their fetuses were 28 weeks gestational age (GA) and continued to do so until their fetuses reached 34 weeks of age, at which time the recitations stopped. Fetuses' learning and memory of their rhyme were assessed at 28, 32, 33, 34, 36 and 38 weeks. The criterion for learning and memory was the occurrence of a stimulus-elicited heart rate deceleration following onset of a recording of the passage spoken by a female stranger. Detection of a sustained heart rate deceleration began to emerge by 34 weeks GA and was statistically evident at 38 weeks GA. Thus, fetuses begin to show evidence of learning by 34 weeks GA and, without any further exposure to it, are capable of remembering until just prior to birth. Further study using dose–response curves is needed in order to more fully understand how ongoing experience, in the context of ongoing development in the last trimester of pregnancy, affects learning and memory.

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1. Introduction

During prenatal development a mother's speech/voice sounds are salient, rising above other intrauterine sounds by as much as 24 decibels (dB) (Gerhardt, 1989; Querleu, Renard, Boutteville, & Crepin, 1989; Richards, Frentzen, Gerhardt, McCann, & Abrams, 1992; Zatorre, Belin, & Penhune, 2002). Prenatal exposure to the mother's speech/voice is postulated to influence early speech perception based on that notion that her speech and voice sounds have become familiar and thus, different from other's voices and speech, e.g. non-native speech (Busnel, Granier-Deferre, & Lecanuet, 1992; DeCasper & Prescott, 2009; Fifer & Moon, 1994; Kisilevsky & Hains, 2010). The objective of this study was to provide a six week controlled history of fetal exposure to a specific passage of speech recited by the mother during early fetal development (28–34 weeks gestational age), and describe the fetal cardiac response both during the six weeks controlled exposure period and afterward with a recording of the same (or different) passage of speech recited by a stranger. Thus, we could determine when in early fetal development the passage, per se, first became familiar and, subsequently, how long it could be remembered.

The occurrence of a stimulus elicited cardiac deceleration or the cardiac orienting response was used to assess learning and memory. The conventional interpretation of a stimulus-elicited heart-rate deceleration is that it represents the cardiac component of the orienting response. Current theoretical interpretations of the fetal cardiac response to speech vary (Catania, 1984; Clarkson & Berg, 1983; Graham & Clifton, 1966; Kisilevsky, Fearon, & Muir, 1998; Porges, 1995, 2007; Reynolds &

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Richards, 2008; Schneirla, 1961). In relation to theoretical interpretation derived from the learning literature, one of the three learning processes (habituation, respondant, and operant conditioning) could be considered (Catania, 1984). Further, another body of literature would interpret their findings as attention or perception. The process(es) by which detection of cardiac orienting to speech is, therefore, unknown. What can be considered, however, is the fetal experience in relation to the maturational status of both the autonomic nervous system (ANS) and central nervous system (CNS) functioning during early fetal development and insights related to the physiological basis of the cardiac orienting response.

More specifically, involvement of the parasympathetic branch of the ANS during cardiac orienting is founded on both fetal and preterm infant descriptions of the ANS control of cardiac activity, movement, and heart rate variability. As with 28–34 week postmenstrual age preterm infants (Krueger, vanOostrom, & Shuster, 2010), the fetus at a similar age typically demonstrates a significant increasing trend in the parasympathetic control of heart rate variability (Kotini et al., 2001). This increase in the influence of the parasympathetic branch of the ANS on cardiac activity coincides with behavioral studies in which cardiac reactions elicited by fetal movement (Gagnon, 1989) and loud sounds occur reliably only after about 32 weeks' gestation. Thus, ANS control of cardiac activity, movement, and heart rate variability (HRV) is maturing significantly during this time (DiPetro, Hodgson, Costigan, Hilton, & Johnson, 1996; Groome, Loizou, Holland, Smith, & Hoff, 1999; Holmes, 1986) and is the reason why, it was chosen here, as a time period during which cardiac changes in response to a passage of speech (orienting response) could be interpreted as an early indication of learning.

1.1. Fetal cardiac responses to sound

Multiple factors can affect when and how a fetus responds to sound. The most obvious classes of events are maturational and acoustical. Several relevant examples follow. Fetuses do not respond to changes in the frequencies of sound until 28 weeks gestation, three weeks after the cochlea and peripheral sensory end organs are structurally complete (Holst et al., 2005; Lasky & Williams, 2005). When the fetus is between 32 and 34 weeks gestational age, the cardiac response to white noise presented at 85 dB is sometimes an acceleration and sometimes a deceleration, whereas when the fetus is between 35 and 37 weeks gestational age, the cardiac response is consistently a deceleration (Morokuma et al., 2008). See also (DiPetro et al., 1996; Gagnon, Patrick, Foreman, & West, 1986; Groome, Mooney, Holland, & Bentz, 1997). Human sleep-wake states or activity cycles begin developing before birth and significantly affecting stimulus-elicited cardiac activity. Alternations between active and inactive states are not obvious before 30 weeks GA and periods of low heart-rate variability (LHRV) of <5 bpm are infrequent. After 32 weeks GA activity/inactivity cycles become more discernible and around 36 weeks GA clearly differentiated sleep-wake states become apparent, 1F/sleep and 3F/awake are periods of LHRV and 2F/sleep and 4F/awake are periods of high heart-rate variability (Nijhuis, Prechtl, Martin, & Bots, 1982). The term fetus, while in 1F/sleep and 3F/awake periods of LHRV, responds to high intensity sound (>85 dB) with a cardiac acceleration which transitions to a cardiac deceleration as sound intensity decreases to a lower level (<85 dB) (Lecanuet, Granier-Deferre, Cohen, Le Houezec, & Busnel, 1986). This transition to a predominant cardiac deceleration, however, only occurs when the sound is within the frequency range of human speech. Higher frequencies result in a predominant cardiac acceleration (Lecanuet, Granier-Deferre, & Busnel, 1988), which suggests that fetuses are differentially sensitive to frequencies in the speech range. See also (Granier-Deferre, Ribeiro, Jacquet, & Bassereau, 2011; Lecanuet et al., 1986; Lecanuet, Granier-Deferre, Jacquet, & Busnel, 1992).

When the variables noted above have been controlled, it has been possible to demonstrate that prior experience with the stimulus can also affect the cardiac response it elicits, i.e., that late-term fetuses can learn about and remember specific sounds. For example, fetuses in the late prenatal period were consistently exposed to a descending pattern of music that was within the frequency range of speech, until they were 38 weeks GA. When these same subjects were one-month old infants they and a group of naïve one-month olds were tested with the descending pattern and with a different, ascending pattern. The descending pattern elicited a profound cardiac deceleration in infants that had been exposed to it before birth compared to a much lesser deceleration in naïve infants. Infants that had been exposed to the descending pattern and naïve infants, responded to the ascending pattern with the lesser deceleration (Granier-Deferre, Bassereau, Ribeiro, Jacquet, & Decasper, 2011a). Thus, stimulus-elicited cardiac responses have been able to show that fetal exposure to a specific sound within the frequency range of speech late in gestation can have a powerful impact on auditory perception as long as one-month after birth.

1.2. Testing fetal responses to maternal speech

When cardiac orienting responses are used to assess learning and memory of maternal speech, the importance of controlling relevant factors becomes critical when trying to interpret the data. For example, when the ages of fetuses varies within and between groups, when fetal state is not controlled, when control over the history of exposure to maternal speech is absent or very brief (2 min) and the intensity of the test stimulus is high (>85 dB), the predominant response to speech recorded by the mother is a cardiac acceleration and the response to a stranger's recording of the same passage is a cardiac deceleration (Kisilevsky & Hains, 2011; Kisilevsky et al., 2003, 2009, 2011; Lee, Brown, Hains, & Kisilevsky, 2007; Smith, Dmochowski, Muir, & Kisilevsky, 2007). When the fetus' history of exposure to the mother 's recitation of the passage is weeks long and the conditions of exposure and the conditions of testing are similar (all fetuses are near term and in a low activity state and the test stimuli are presented at lower intensity or <85 dB), the predominant cardiac response is a cardiac deceleration—the