

Positive Bias in Emotional Speech Processing in Newborns: Evidence from Event-Related Potentials

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Abstract

Accurately decoding emotional information from speech facilitates adaptive functioning in social environments. This capacity is especially critical for newborns and infants, as the human auditory system is considerably more mature than the visual system at birth. Although existing studies have demonstrated that infants aged 5-7 months can discriminate between different categories of emotional speech, research on newborns is extremely limited. Whether humans are endowed at birth with the ability to discriminate different types of emotional speech, and whether emotion processing in newborns demonstrates a positive or negative bias, remains unknown. The present study utilized the odd-ball paradigm to examine event-related potentials elicited in the brains of newborns aged 1-6 days by three categories of prosodic emotional speech: happy, fearful, and angry. Experiment 1 directly contrasted the three emotional conditions and revealed that frontal regions of the newborn brain (electrode sites F3 and F4) could discriminate the valence of emotional speech, with the mismatch response elicited by positive (happy) speech exhibiting significantly greater amplitude than that evoked by negative (angry and fearful) speech. Experiment 2 employed a reversed odd-ball paradigm with swapped deviant and standard stimuli, confirming that the findings of Experiment 1 did not stem from acoustic differences among the three emotional speech stimuli. These results indicate that the newborn brain is capable of automatically discriminating between positive and negative emotional speech, but is not yet capable of distinguishing between the two negative emotions of anger and fear. Critically, happy speech evoked a larger mismatch response than the two negative speech types, providing the first neurophysiological evidence (electrophysiological indices) of a positivity bias in emotional speech processing in newborns.

Full Text

Early Preference for Positive Over Negative Prosody in Neonates: Evidence from Event-Related Potentials

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Abstract

Accurate decoding of emotional information from vocal cues is essential for adaptive social functioning. This capacity is particularly critical for newborns and infants, as the auditory system is far more developed than the visual system at birth. While previous research has demonstrated that 5- to 7-month-old infants can discriminate among different emotional vocalizations, few studies have examined this ability in neonates. Are humans born with the capacity to differentiate emotional prosody? Moreover, does emotional processing in newborns exhibit a positivity or negativity bias? Using an oddball paradigm, we investigated event-related potentials (ERPs) elicited by happy, fearful, and angry prosodic speech in 1- to 6-day-old neonates. In Experiment 1, which directly compared the three emotional conditions, we found that the neonatal frontal cortex (at electrodes F3 and F4) could discriminate the valence of emotional prosody, with positive (happy) voices eliciting significantly larger mismatch responses (MMR) than negative (angry and fearful) voices. Experiment 2 employed a reversed oddball paradigm (swapping deviant and standard stimuli) to confirm that these results were not attributable to physical differences among the three emotional stimuli. Our findings suggest that the neonatal brain can automatically discriminate between positive and negative emotional prosody, but cannot yet differentiate between the two negative emotions (anger and fear). More importantly, the larger MMR elicited by happy voices compared to negative voices provides, for the first time, neurophysiological evidence for a positivity bias in neonatal emotional prosody processing.

Keywords: neonate; positivity bias; happy prosody; fearful prosody; angry prosody

Introduction

Speech is the most frequently encountered sound type in daily life, conveying not only semantic information but also the speaker's emotional state (Belin,

Fecteau, & Bédard, 2004). Accurate decoding of emotional information from vocal cues enables individuals to better adapt to social environments (Decety & Howard, 2013; Frühholz & Grandjean, 2013; Hawk, Van Kleef, Fischer, & Van der Schalk, 2009). During early development, newborns (0–28 days) and infants (1–12 months) possess a far more mature auditory system than visual system, making vocal emotion more critical for survival and development than facial expressions and other visual carriers of emotion (Grossmann, 2010; Vaish, Grossmann, & Woodward, 2008; Vaish & Striano, 2004).

Emotion in speech can be conveyed through semantics or through the combination of acoustic features such as frequency, intensity, and rhythm (Brük, Kreifelts, & Wildgruber, 2011). Given that young infants, particularly neonates, lack semantic comprehension, the present study focuses exclusively on the processing of emotional prosody. The neonatal auditory system is fully capable of processing pitch (Háden et al., 2009), with the right superior temporal sulcus and middle temporal gyrus showing significantly greater activation to varying prosody than the left hemisphere (Arimitsu et al., 2011; Telkemeyer et al., 2009). Additionally, neonatal frontal lobes show specific activation to speech with varying pitch compared to monotonic speech, suggesting that the brain at this developmental stage can already differentiate different prosodic patterns (Saito et al., 2007).

Regarding emotional prosody (or melody) processing, although previous studies have shown that 5-month-old infants can distinguish between sad and happy melodies while listening to music (Flom & Pick, 2012) and that 5- to 7-month-old infants can discriminate different emotional categories in speech (Flom & Bahrick, 2007), and that 7-month-old infants can detect congruent emotional information across faces and voices (Grossmann, Striano, & Friederici, 2005), research on the neonatal period immediately after birth remains scarce. Are humans born with the ability to discriminate among different categories of emotional prosody? If so, does emotional processing in neonates exhibit a positivity or negativity bias? This second question arises from the following observations: children, adolescents, and adults exhibit a negativity bias in emotional information processing—that is, they allocate greater attentional, evaluative, and memorial resources to negative information (Ito, Larsen, Smith, & Cacioppo, 1998). However, this negativity bias does not appear to be innate. Vaish et al. (2008) reviewed face and voice studies and found that infants only begin to show a clear processing bias toward negative emotions after 6–7 months of age. For example, in the visual domain, 6-month-old infants showed larger central negative ERP components when viewing objects previously cued by fearful (versus neutral) faces (Hoehl & Striano, 2010), and 7-month-olds looked longer at fearful (versus happy) faces and exhibited larger central negative components (Peltola, Leppänen, Mäki, & Hietanen, 2009). In the auditory domain, 7-month-old infants showed significant right temporal activation to angry (versus happy and neutral) prosody, along with larger frontal and central negative components (Grossmann et al., 2005; Grossmann, Oberecker, Koch, & Friederici, 2010). In contrast, studies supporting an early positivity bias have shown that 5-month-

old infants exhibit more smiling responses when listening to approving (versus disapproving) speech (Fernald, 1993), and 4-month-olds look longer at happy faces than at angry and neutral faces (LaBarbera, Izard, Vietze, & Parisi, 1976), while also showing larger frontal and central negative components to objects cued by happy (versus fearful) faces (Rigato, Farroni, & Johnson, 2010). However, these studies on positivity and negativity biases only examined infants older than 3 months, with very few reports on younger infants, particularly neonates.

To our knowledge, only three studies have directly compared neonatal processing of positive and negative emotional materials. An early behavioral study found that happy speech elicited longer eye-opening responses in neonates compared to angry, sad, and neutral speech (Mastropieri & Turkewitz, 1999). A more recent behavioral study examining looking times to happy and fearful faces found that neonates looked longer at happy faces (Farroni, Menon, Rigato, & Johnson, 2007). Subsequently, Cheng et al. (2012) used an oddball paradigm to study ERPs in neonates processing emotional prosody, providing the first neurophysiological evidence that neonates can discriminate vocal emotions. That study found that fearful prosody elicited larger mismatch potentials than happy prosody in frontal-central regions. Since this ERP component appears as a positive amplitude in neonates (Dehaene-Lambertz, 2000; Friederici, Friedrich, & Weber, 2002; Leppänen et al., 2004; Ruusuvirta, Huotilainen, Fellman, & Näätänen, 2009; Winkler et al., 2003)—opposite in polarity to the mismatch negativity typically found in adults—we refer to this component as the “mismatch response” (MMR; Cheng et al., 2012; Zhang et al., 2014). Notably, these three neonatal studies provide contradictory answers regarding positivity versus negativity bias: the two behavioral studies support a positivity bias, while Cheng et al. (2012) support a negativity bias.

In summary, research on neonatal emotional prosody processing remains extremely limited, with seemingly contradictory conclusions regarding emotional processing biases. Neonates represent a special population that cannot remain quiet and focused according to the experimenter’s instructions, and movement artifacts during experiments can significantly interfere with behavioral and neural measures. Therefore, cumulative evidence is needed to draw reliable conclusions. The present study aims to address this gap through two experiments using ERP technology to examine neonatal brain responses to happy, angry, and fearful prosody. Following Cheng et al. (2012), we employed the oddball paradigm because it offers higher sensitivity in detecting discrimination abilities than other passive task paradigms (e.g., presenting two stimulus types with equal probability; Ferrari, Bradley, Codispoti, & Lang, 2010). Experiment 1 used a classic oddball paradigm with three blocks to elicit ERP waveforms for each emotional prosody, examining neonatal brain sensitivity to emotional valence by directly comparing MMR amplitudes across the three conditions. Experiment 2 used a reversed oddball paradigm (swapping deviant and standard stimuli) to both replicate Experiment 1 and rule out the possibility that MMR differences among emotions in Experiment 1 were due to physical differences

among the emotional stimuli. We used the same experimental materials as Cheng et al. (2012). Based on their results, we hypothesized that humans are born with the ability to discriminate positive and negative emotional prosody and may exhibit a processing bias toward negative emotions, with angry and/or fearful prosody eliciting larger MMR amplitudes than happy prosody.

Method

Participants

Experiments 1 and 2 recruited 25 and 35 healthy full-term neonates within one week of birth, respectively. Seven and six participants failed to complete data collection due to crying (excessive EEG artifacts), leaving 18 valid participants in Experiment 1 (9 male, 9 female; gestational age 38.9 ± 0.9 weeks; age 3.2 ± 1.3 days) and 29 in Experiment 2 (15 male, 14 female; gestational age 38.7 ± 1.0 weeks; age 2.8 ± 1.2 days). Inclusion criteria were: (1) birth weight appropriate for gestational age; (2) no abnormal clinical manifestations before or during the experiment; (3) no sedatives administered within 48 hours before testing; (4) no hearing impairment detected by otoacoustic emission screening (OAE, ILO88 Dpi, Otodynamics Ltd, Hatfield, UK); (5) Apgar scores 9 at 1 and 5 minutes after birth; and (6) no abnormal neurological findings at 6-month follow-up. Exclusion criteria included: (1) hypoxic-ischemic encephalopathy; (2) intraventricular hemorrhage or white matter injury (ultrasound); (3) severe congenital malformations; (4) central nervous system infection; (5) metabolic disorders; and (6) seizures or epilepsy (clinical presentation). Parents were informed of the study purpose and procedures, and provided written informed consent. The experimental protocol was approved by the Peking University Medical Ethics Committee.

Materials

We used the emotional prosody materials from Cheng et al. (2012), whose validity has been confirmed in multiple studies (e.g., Fan, Hsu, & Cheng, 2013; Hung, Ahveninen, & Cheng, 2013; Zhang et al., 2014). The experiment used four two-syllable “dada” utterances expressing four emotions: angry, fearful, happy, and neutral [Figure 1: see original paper].

The materials were created as follows: a young adult female produced 15 repetitions of “dada” in each of the four emotional conditions. These 60 utterances were rated by 120 adults on a 5-point scale for emotion type and intensity. The four utterances receiving the highest ratings for each emotion were selected as experimental stimuli and edited to identical length and intensity using Adobe Audition (Adobe Systems Inc., San Jose, USA).

Procedure

The experiment was conducted in the pediatric ward of Peking University First Hospital, with background noise of approximately 30 dB SPL (Xima Sound Level Meter AS804, Dongguan Wanchuang Electronic Products Co., Ltd., Dongguan, China). Stimuli were presented through in-ear active noise-canceling headphones (IER-NW500N, Sony Corp., Tokyo, Japan) at an average intensity of 50 dB SPL.

Experimental preparation (EEG electrode placement, etc.) began 10 minutes after feeding and lasted less than 10 minutes. The laboratory was then kept quiet to allow infants to fall asleep naturally. Amplitude-integrated EEG (Olympic CFM 6000, Natus, Seattle, USA) was used to monitor sleep-wake status in real-time [Figure 2: see original paper]A, with electrodes placed at CP3 and CP4 positions. This sleep monitor was independent of the EEG system used for data collection. Stimulus presentation began 3–5 minutes after infants entered “active sleep”(equivalent to adult REM sleep). For details on amplitude-integrated EEG technology and neonatal sleep staging, see our previous publications (Zhang et al., 2011; 2014).

The experiment used an oddball paradigm (Cheng et al., 2012; Zhang et al., 2014) in which infants passively listened to emotional prosody during sleep. The task consisted of three blocks (happy, angry, fearful) with 10-second intervals between blocks; block order was counterbalanced across participants. Each block contained 500 trials: 400 standard stimuli and 100 deviant stimuli, with at least two standard stimuli between successive deviants. Each stimulus lasted 350 ms, with inter-stimulus intervals of 450–850 ms (Hirasawa, Kurihara, & Konishi, 2002; Zhang et al., 2014), resulting in a total duration of 500 seconds (8.3 minutes) per block.

Experiment 1 comprised one session in which each neonate listened to one block each of happy, angry, and fearful prosody, with emotional voices as deviant stimuli and neutral prosody as the standard stimulus. Experiment 2 comprised two sessions, each including one block of happy, angry, and fearful prosody. In one session, emotional voices served as deviants and neutral prosody as standards; in the other session, this relationship was reversed (emotional voices as standards, neutral prosody as deviant). Each neonate completed both sessions, with session order counterbalanced across participants.

Data Acquisition and Analysis

EEG data were recorded using a HANDYEEG system (Micromed, Treviso, Italy) at a sampling rate of 256 Hz, with electrode-scalp impedance below 5 k Ω . The left mastoid served as the reference electrode. Consistent with previous research (Cheng et al., 2012; Zhang et al., 2014), Experiment 1 examined EEG signals at six electrodes: F3, F4, C3, C4, P3, and P4 [Figure 2: see original paper]B. Based on Cheng et al. (2012) and our Experiment 1 results, Experiment 2 simplified data acquisition to examine only F3 and F4.

Offline analysis included re-referencing to the average of both mastoids, filtering (0.01–30 Hz), epoching (–200 to 1000 ms), baseline correction (–200 to 0 ms), and rejection of trials with amplitudes exceeding ± 150 V. MMR mean amplitude was measured in the 300–500 ms window following stimulus onset (Cheng et al., 2012; Zhang et al., 2014).

Statistical analysis was performed using SPSS Statistics 20.0 (IBM Corp., Somers, USA). Descriptive statistics are presented as mean \pm standard deviation. The significance level was set at $p < 0.05$, with Bonferroni correction for multiple comparisons. Degrees of freedom were adjusted using the Greenhouse–Geisser method. Two-way repeated-measures ANOVAs were conducted on MMR mean amplitudes, with within-subject factors of emotion type (angry, fearful, happy) and electrode site (Experiment 1: F3, F4, C3, C4, P3, P4; Experiment 2: F3, F4).

Experiment 1 did not use traditional “difference waves” but instead directly compared MMR amplitudes across the three emotional conditions based on raw waveforms (as in Cheng et al., 2012). This approach was necessary because, compared to healthy adults, neonatal ERP data have extremely low signal-to-noise ratios (primarily due to movement artifacts), and using difference waves would introduce substantial noise by subtracting the standard condition’s noise into all emotional conditions.

Experiment 2 employed the reversed oddball paradigm, requiring calculation of difference waves between deviant and standard stimuli for the same emotional voice (e.g., the happy difference wave equaled the ERP when happy served as deviant minus the ERP when happy served as standard). Given the low signal-to-noise ratio of difference waves, Experiment 2 recruited more participants than Experiment 1 (29 vs. 18) to enhance statistical power.

Results

Experiment 1

The main effect of emotion was significant ($F(2,34) = 5.27$, $p = 0.012$, $\eta^2 = 0.235$): happy prosody elicited larger MMR amplitudes (absolute amplitude: 3.49 ± 1.23 V) than angry prosody (2.90 ± 1.25 V, $p = 0.010$). MMR amplitudes did not differ significantly between happy and fearful conditions (3.12 ± 1.18 V, $p = 0.138$) or between fearful and angry conditions ($p = 0.893$). The main effect of electrode site was not significant ($F(5,85) < 1$). The emotion \times electrode interaction was significant ($F(10,170) = 2.41$, $p = 0.025$, $\eta^2 = 0.125$; [Figure 3: see original paper]). Simple effects analysis revealed a significant emotion effect at electrode F3 ($F(2,34) = 13.94$, $p < 0.001$): happy prosody elicited larger MMR (3.92 ± 1.17 V) than angry prosody (2.40 ± 1.33 V, $p < 0.001$) and marginally larger MMR than fearful prosody (3.15 ± 1.02 V, $p = 0.059$). Fearful and angry conditions did not differ ($p = 0.077$). At electrode F4, the emotion effect was also significant ($F(2,34) = 21.12$, $p < 0.001$): happy prosody elicited larger MMR (3.88 ± 1.07 V) than both angry (2.77 ± 0.90 V,

$p < 0.001$) and fearful prosody (2.93 ± 1.07 V, $p = 0.001$), while fearful and angry conditions did not differ ($p = 1.000$). No significant emotion effects were observed at the other four electrodes ($F(2,34) < 1$).

Experiment 2

We obtained waveforms for the three emotional conditions when they served as deviant stimuli [Figure 4: see original paper]A and standard stimuli [Figure 4: see original paper]B, and calculated difference waves between deviant and standard for the same emotional voice [Figure 4: see original paper]C. When emotional voices served as deviants, the main effect of emotion was significant ($F(2,56) = 6.94$, $p = 0.002$, $\eta^2 = 0.197$; [Figure 4: see original paper]A): happy prosody elicited larger MMR (absolute amplitude: 3.38 ± 1.14 V) than angry (2.23 ± 1.56 V, $p = 0.009$) and fearful prosody (2.37 ± 1.37 V, $p = 0.008$), while fearful and angry conditions did not differ ($p = 1.000$). The main effect of electrode site was not significant ($F(1,28) < 1$). When emotional voices served as standards, no significant emotion effect emerged ($F(2,56) < 1$; happy = 1.45 ± 1.06 V, angry = 1.43 ± 1.19 V, fearful = 1.54 ± 1.15 V; [Figure 4: see original paper]B), and the electrode main effect was not significant ($F(1,28) < 1$). Analysis of difference waves revealed a significant main effect of emotion ($F(2,56) = 4.14$, $p = 0.021$, $\eta^2 = 0.129$; [Figure 4: see original paper]C): happy prosody elicited larger difference waves (1.97 ± 1.64 V) than angry (0.75 ± 1.72 V, $p = 0.058$, marginally significant) and fearful prosody (0.88 ± 1.81 V, $p = 0.048$), while fearful and angry conditions did not differ ($p = 1.000$). The electrode main effect was not significant ($F(1,28) < 1$).

Discussion

The present study used ERP technology to investigate neural responses in sleeping neonates (average age 3 days) during passive listening to different emotional prosodies (happy, angry, fearful). We found that the neonatal frontal cortex (F3 and F4 electrodes) could discriminate the valence of emotional prosody, with positive (happy) voices eliciting significantly larger MMR amplitudes than negative (angry and fearful) voices. This result provides the first neurophysiological evidence for a positivity bias in neonatal emotional prosody processing.

The MMR examined here is a positive ERP component elicited by deviant stimuli (relative to standards) in neonates, analogous to the mismatch negativity (MMN) generated in adult frontal (or fronto-central) regions. The auditory MMN typically peaks 150–250 ms after stimulus onset and is obtained by subtracting the standard stimulus waveform from the deviant stimulus waveform, yielding a negative displacement (Näätänen, Paavilainen, Rinne, & Alho, 2007). The MMN reflects automatic detection of stimulus differences and, because its generation does not require attentional involvement, is considered one of the most suitable ERP components for infant brain function research. The MMR observed in neonates and other infant auditory studies (Cheng et al., 2014;

Dehaene-Lambertz, 2000; Friederici et al., 2002; Leppänen et al., 2004; Ruusu-virta et al., 2009; Winkler et al., 2003) can be viewed as an early developmental precursor of the MMN. Due to the extreme immaturity of the neonatal brain, the MMR at this stage appears as a positive component with delayed latency. Source localization studies have identified the neural generator of MMN/MMR in the superior temporal sulcus (STS), particularly the right STS, which is precisely the brain region involved in emotional prosody processing in adults (Belin, Zatorre, Lafaille, Ahad, & Pike, 2000; Ethofer et al., 2012). Although the low spatial resolution of ERP technology prevents us from asserting that the core brain regions for emotional prosody processing are functionally differentiated at birth, our results at least demonstrate that humans can automatically discriminate the valence of emotional prosody from birth and are more sensitive to positive emotional information.

Our finding of a positivity bias in neonatal emotion processing contradicts our initial hypothesis and the results of Cheng et al. (2012). We propose three possible reasons for this discrepancy. First, Cheng et al. (2012) used a variant of the oddball paradigm (random design) in which two deviant stimuli (happy and fearful voices) were each presented with 10% probability among standard stimuli (neutral voice). They found that fearful prosody elicited larger MMR than happy prosody. Our study used a classic oddball paradigm (block design) in which happy, angry, and fearful voices each served as deviants with 20% probability across three separate blocks, revealing larger MMR for happy prosody. We suggest that Cheng et al.'s random design, which mixed happy and fearful voices within the same time period, may have caused partial cancellation between the positive and negative emotional effects, reducing result validity. Which oddball design is more suitable for addressing this question requires further investigation; we merely offer this as a potential explanation for the inconsistent findings. Second, Cheng et al. (2012) conducted their experiment while neonates were both awake and asleep, whereas we strictly controlled participant state by collecting ERP data only during active sleep (similar to adult REM sleep). Given that MMN/MMR is influenced by sleep-wake status (Hirasawa et al., 2002; Zhang et al., 2014), this could account for the divergent results. Third, due to eye and body movement artifacts, neonatal ERP data have substantially lower signal-to-noise ratios than adult data, reducing the reliability of single-study results. We therefore believe that a series of cumulative experiments is necessary to provide definitive answers regarding neonatal emotional biases.

The present study provides the first neurophysiological evidence for a positivity bias in neonatal emotion processing, extending the behavioral findings of Mastropieri et al. (1999) and Farroni et al. (2007). Additional research indirectly supports positivity preferences in neonates. For instance, numerous studies have found that neonates prefer infant-directed speech (IDS)—characterized by higher pitch, exaggerated stress, and more cheerful intonation—over adult-directed speech (Cooper & Aslin, 1990; Singh, Morgan, & Best, 2002), with IDS specifically activating neonatal frontal regions (Saito et al., 2007). Neonates also prefer their mother's voice over strangers' voices (DeCasper &

Fifer, 1980). One possible explanation is that IDS and maternal voices typically express more positive emotion (Saito, Fukuhara, Aoyama, & Toshima, 2009; Singh et al., 2002), providing indirect evidence for a positivity bias. As previously noted, while negativity bias is a well-established phenomenon in emotional processing, it only becomes reliably observable after 6–7 months of age; younger infants appear more interested in positive emotional information (Vaish et al., 2008). The developmental shift from positivity to negativity bias can be explained by the range-frequency hypothesis (Parducci, 1995). In brief, neonates and young infants frequently receive positive emotional signals from caregivers. Learning to associate caregivers' positive emotional cues (e.g., happy voices or expressions) with nurturing care (holding, touching, feeding) helps them obtain more physical and psychological comfort. Conversely, they are rarely exposed to negative emotional environments at this stage, and their limited motor abilities prevent them from actively escaping danger, so increased attention to negative cues provides minimal survival advantage. After 6–7 months, however, infants' rapidly developing motor skills enable active exploration of their environment, accompanied by increasing negative signals from caregivers (e.g., frightened expressions or reprimands). Infants must then process negative information more quickly and accurately to avoid harm (e.g., Grossmann et al., 2005; 2010; Hoehl & Striano, 2010; Peltola et al., 2009). Thus, infants first show a positivity bias that later transforms into a negativity bias, a pattern crucial for early development. Understanding this developmental trajectory can inform more scientific parenting approaches and help identify children with emotional and cognitive developmental disorders (e.g., autism) at an early stage.

In conclusion, this study addressed two questions: Can neonates discriminate among different emotion categories? And do they exhibit positivity or negativity biases in emotional information processing? Using classic and reversed oddball paradigms, we examined MMRs elicited by happy, angry, and fearful prosody across three blocks. Both experiments consistently demonstrated that the neonatal brain can automatically discriminate between positive and negative emotional prosody but cannot yet differentiate between the two negative emotions (anger and fear). More importantly, happy prosody elicited larger MMR amplitudes than both negative prosodies, providing neurophysiological confirmation of a positivity preference in neonatal emotional prosody processing. We propose that this postnatal positivity bias represents an evolutionarily adaptive cognitive pattern that helps humans obtain more food and caregiver affection during the earliest stages of extrauterine development.

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