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Perinatally Influenced Autonomic System Fluctuations Drive Infant Vocal Sequences

Highlights

- Like human infants, marmoset monkey infants produce babbling-like vocal sequences
- Different vocal elements were dependent upon unique patterns of respiration
- Fluctuations of the autonomic nervous system drove patterns of respiration
- Perinatal experience influenced the physiology underlying vocal sequences

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In Brief

Using marmoset monkeys as a model system, Zhang and Ghazanfar show that infant vocal output is driven by fluctuations of the autonomic nervous system. Comparison of dizygotic twins versus non-twin siblings versus non-siblings showed that these fluctuations are influenced by perinatal experiences.

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Perinatally Influenced Autonomic System Fluctuations Drive Infant Vocal Sequences

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SUMMARY

The variable vocal behavior of human infants is the scaffolding upon which speech and social interactions develop. It is important to know what factors drive this developmentally critical behavioral output. Using marmoset monkeys as a model system, we first addressed whether the initial conditions for vocal output and its sequential structure are perinatally influenced. Using dizygotic twins and Markov analyses of their vocal sequences, we found that in the first postnatal week, twins had more similar vocal sequences to each other than to their non-twin siblings. Moreover, both twins and their siblings had more vocal sequence similarity with each other than with non-sibling infants. Using electromyography, we then investigated the physiological basis of vocal sequence structure by measuring respiration and arousal levels (via changes in heart rate). We tested the hypothesis that early-life influences on vocal output are via fluctuations of the autonomic nervous system (ANS) mediated by vocal biomechanics. We found that arousal levels fluctuate at ~0.1 Hz (the Mayer wave) and that this slow oscillation modulates the amplitude of the faster, ~1.0 Hz respiratory rhythm. The systematic changes in respiratory amplitude result in the different vocalizations that comprise infant vocal sequences. Among twins, the temporal structure of arousal level changes was similar and therefore indicates why their vocal sequences were similar. Our study shows that vocal sequences are tightly linked to respiratory patterns that are modulated by ANS fluctuations and that the temporal structure of ANS fluctuations is perinatally influenced.

INTRODUCTION

Variable, spontaneous behaviors are ubiquitous in young infants and provide the scaffolding for more complex and organized behaviors later in life [1]. These early behaviors primarily reflect the interplay between the infants' arousal states, sensorimotor coordination, and biomechanical conditions [2]. These and other perinatal influences—which include genetic factors, mother-infant synchrony, and sensory experience—all contribute to shaping those initial conditions [3–5]. One prominent example of such spontaneous and variable behavior is the early vocal output of human infants, upon which speech and, more generally, social interactions develop.

While a common endpoint in phonological development is observed under similar language environments, there is great inter-individual variability in the vocal output of infants at early ages [6]. The shape of the trajectory traversed to get to that common endpoint can be very different between individual infants. The differences in vocal output and its acoustic structure are predicted to be associated with the individual state of arousal [7], which is regulated by the autonomic nervous system (ANS) [8]. Recently, neurodevelopmental disorders representing two opposite extremes in social communication—autism and Williams syndrome—have been linked to arousal/ANS dysfunction [9, 10]. These disorders originate very early in development, suggesting strong perinatal determinants [11, 12]. Thus, in order to understand early vocal development (and how it may go awry), it is critical to know how arousal/ANS may function in producing individual differences in vocal output. In this study, we used marmoset monkeys as a model system to investigate these interactions.

Marmoset monkeys (*Callithrix jacchus*) are a voluble New World species that exhibit a complex system of vocal communication that includes vocal turn-taking [13] and cooperative vocal control [14]. Developmentally, marmoset monkeys also go through a babbling stage [15–17], and the maturation rate of infant vocalizations is influenced by vocal feedback from parents [17, 18]. Here, we tested the hypothesis that fluctuations in arousal influence the acoustic structure of babbling-like vocal sequences as they interact with vocal biomechanics (e.g., respiration). Since marmoset monkeys typically give birth to dizygotic twins [19], we could also assess the role of perinatal influences on early vocal behaviors. Relative to their non-twin siblings, we found that twin infants have similar vocal sequence structure, demonstrating an influence of perinatal conditions. We used physiological measures to determine whether ANS fluctuations drive vocal sequences. We found that slow rhythmic fluctuations of the ANS in individual infants modulate the amplitude of respiratory patterns that, in turn, generate the different vocalizations that make up a sequence. The temporal structure of arousal was similar among twins versus non-twins.

RESULTS

We recorded infant vocalizations starting on first postnatal day (P1) and subsequently every 1 to 2 days in a controlled, undirected context (brief social isolation) for 2 months. Our subjects