Prenatal experience with language shapes the brain

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Introduction – speech processing at birth and prenatal experience

1) We know from experience that it is much easier to learn a language as a child than as an adult (‘windows of opportunity’)

2) Language acquisition begins already during the pregnancy period during which the which the foetus can hear sound propagated - albeit distorted - within the womb (?)

3) We hypothesize that newbrons’ brain exhibits **universal (*critical*) and exceptional perception abilities**.

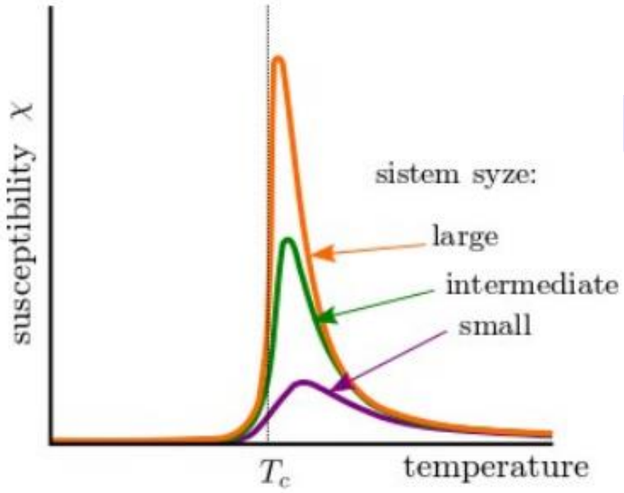
4) We explore whether speech stimulation **induces dynamical changes in newborns' brains**.

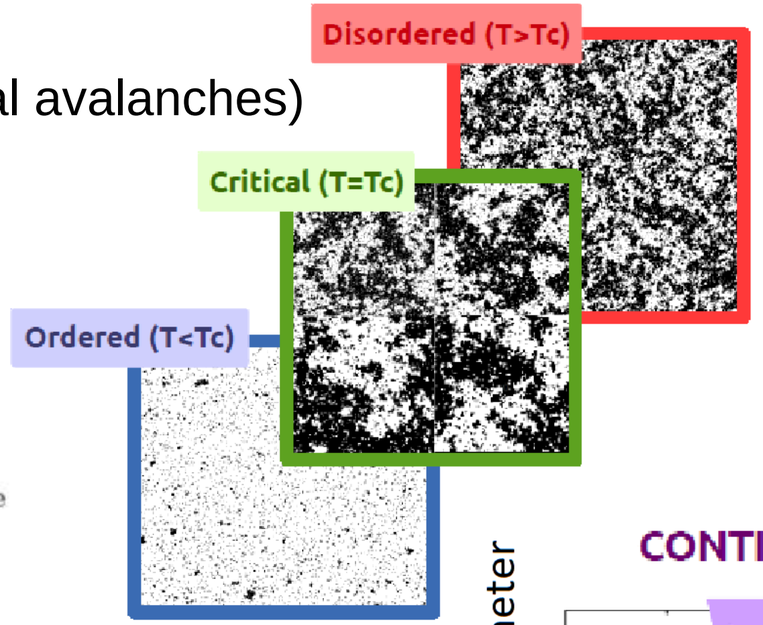
Introduction – criticality and the brain

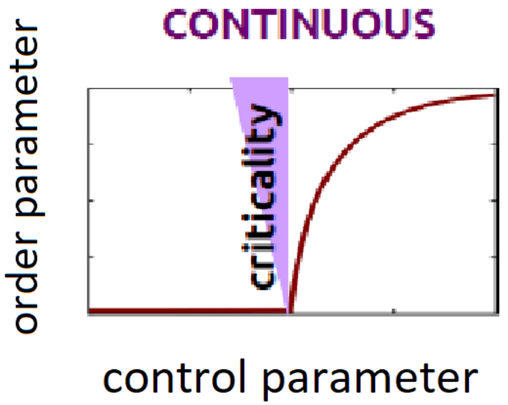
1) Is the newborn brain *Critical*?
   Critical brain hypothesis (2003, Beggs and Plenz, neuronal avalanches)

2) Aspects of criticality:

   - Large scale correlations
   - Very high sensitivity
   - Optimized information processing…







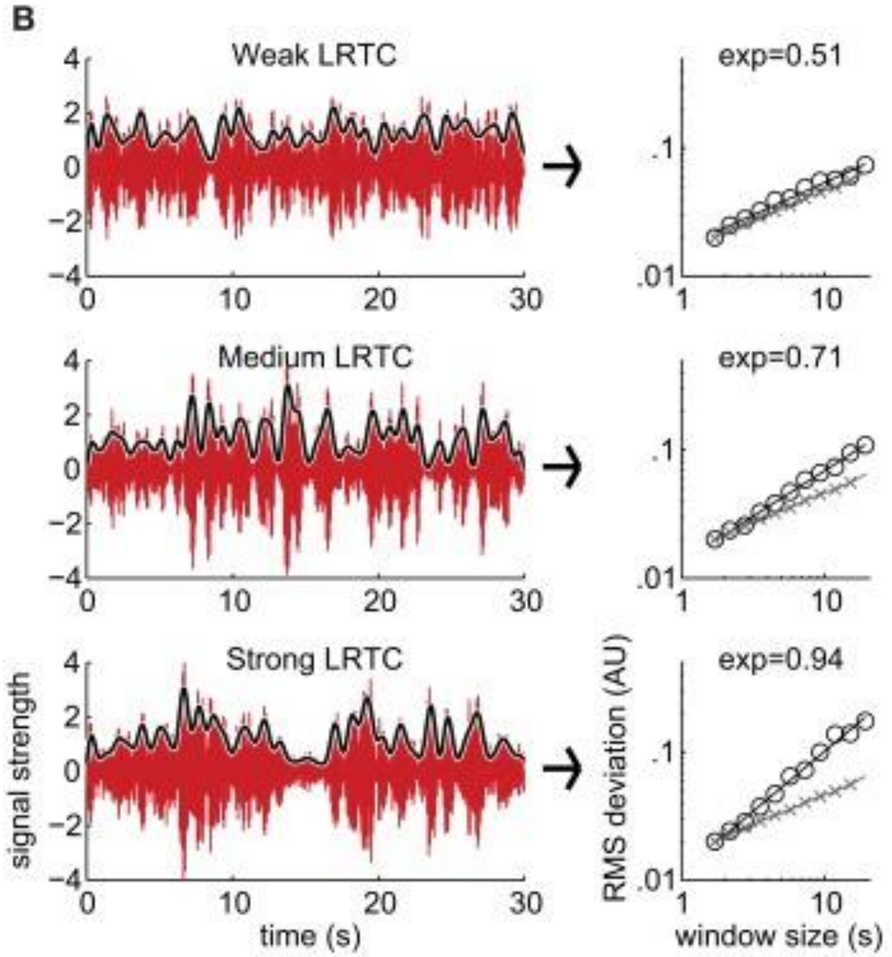
3) Criticality as a biomarker for healty brain (i. e. Alzheimer patients vs controls)

Introduction – criticality and the brain: Detrended Fluctuation Analysis

1) Criticality: **Detrended Fluctuation Analysis → DFA exponent**

2) DFA **Exponent α contains the key to the 'memory' of the neuronal signal**

3) Completely random signal do not show any kind of regularity, or memory. large **α → more memory** → more complex neuronal processes.



Hardstone et al, Frontiers in Physiology, vol 3, year 2012

Questions

1) Does newborns' brain show any sign of **criticality** in terms of DFA exponent?

2) Does **language exposure** affects neural dynamics in the infant brain?

3) Finally, does **prenatal experience** already shape neural circuitry? (slow bands (uterine environment), after listening to French)

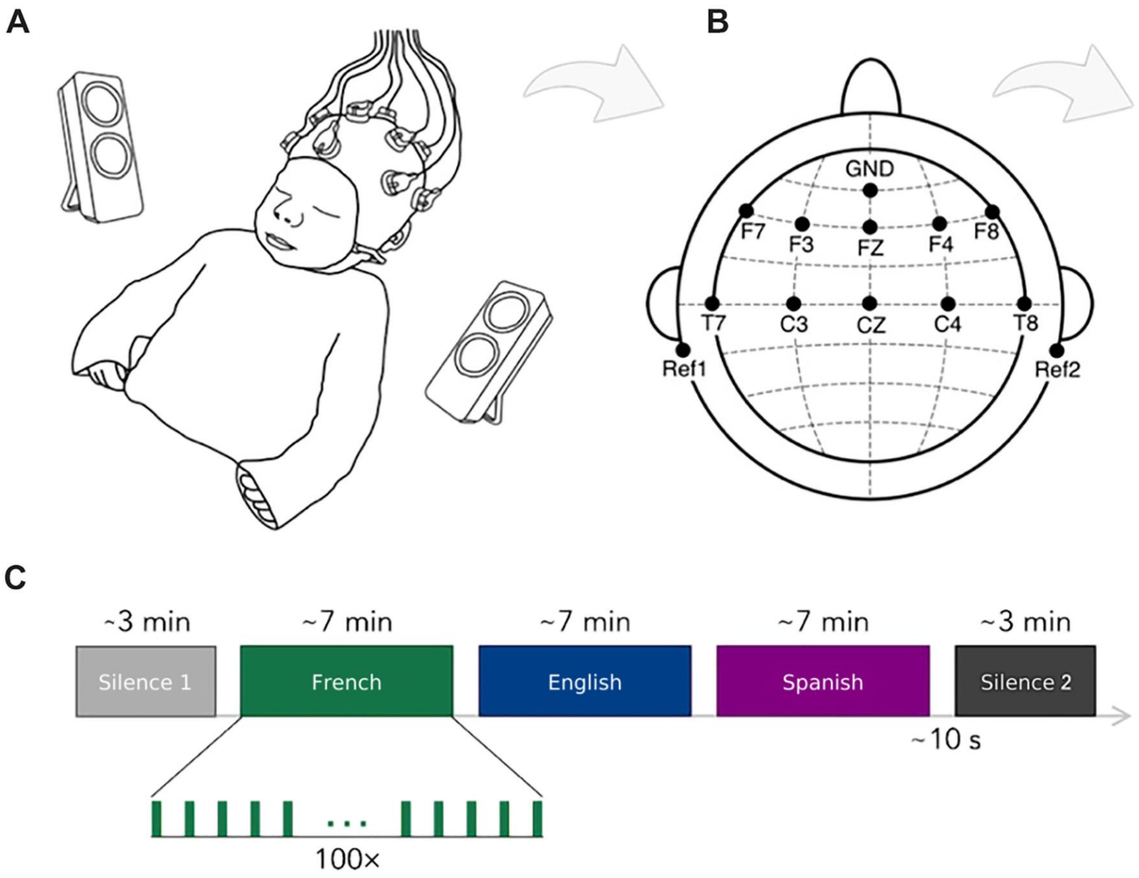
Experimental Setups

1) Total of 49 newborns and excluded 16 after preprocessing: electrophysiological data from 33 were included in the final analysis

2) Five blocks in the experiment**: one initial resting state block (silence 1)**, three *language* blocks, and **one final resting state block (silence 2)**.

3) Speech stimulation: the infants' native language (French), a *rhythmically* similar unfamiliar language (Spanish), and a rhythmically different unfamiliar language (English)

4) EEG data with a 10-channel layout (scalp positions: F7, F3, FZ, F4, F8, T7, C3, CZ, C4, and T8)

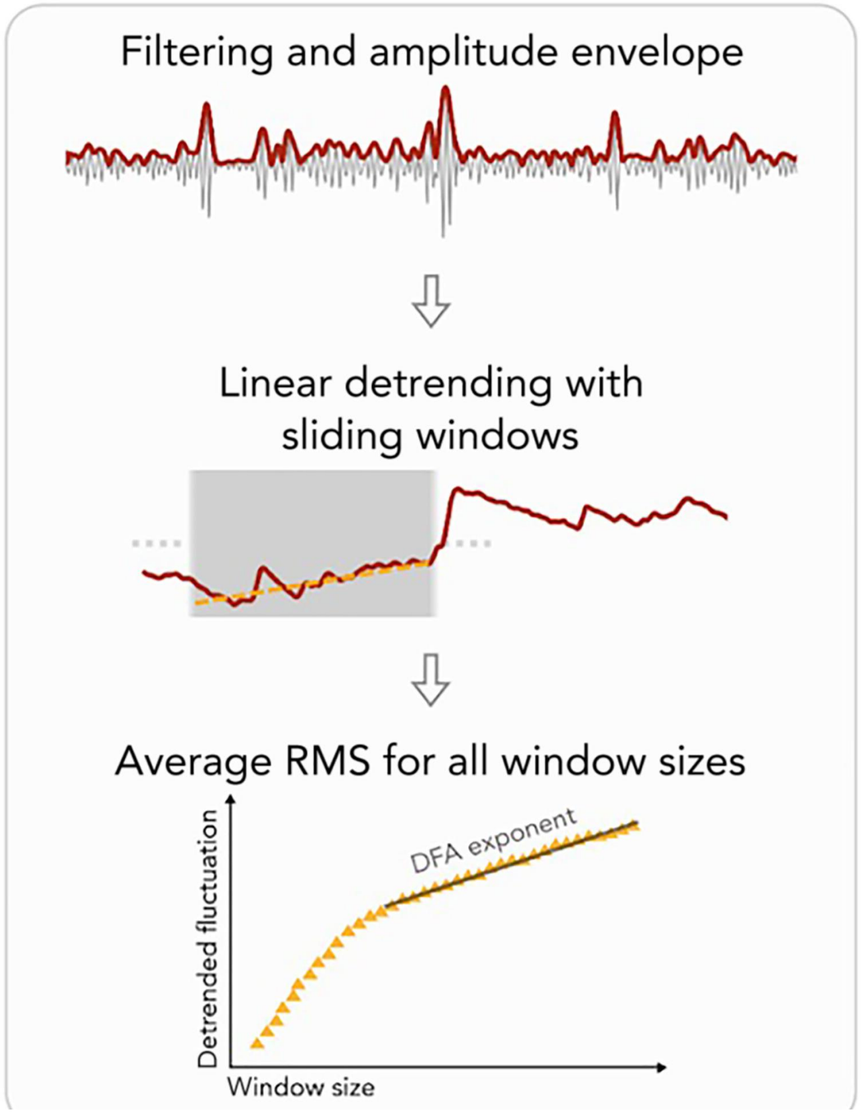


Methods

1) DFA on **the silence 1** and **silence 2** blocks. The signal was filtered in the theta (4 to 8 Hz) and low gamma (30 to 60 Hz) bands.

2) DFA performed on the amplitude envelope of the filtered signals. Split the signals into windows of chosen size with 50% overlap, detrended each window through a least-squares fit, and calculated the SD of the detrended signal.

3) The fluctuation function: the average SD of the detrended signal computed over the windows, as a function of window size. and plot this on a log-log scale

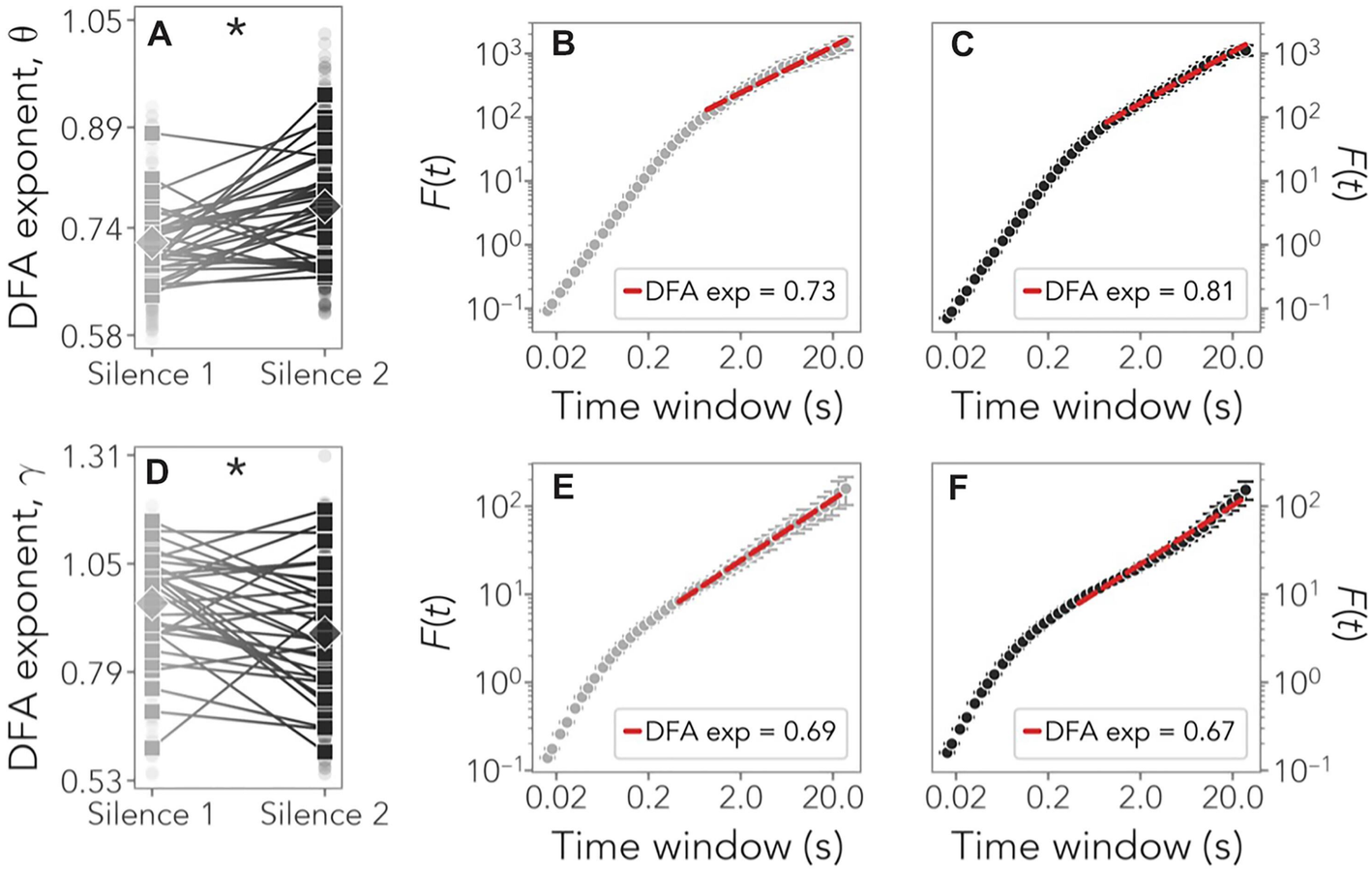


Results 1

1) Oscillations exhibited exponents > 0.7,0.8 (positively correlated memory)

2) Linear mixed-effects model to the DFA exponents with Resting State Period (silence 1/silence 2) as a fixed factor and Participants as a random factor

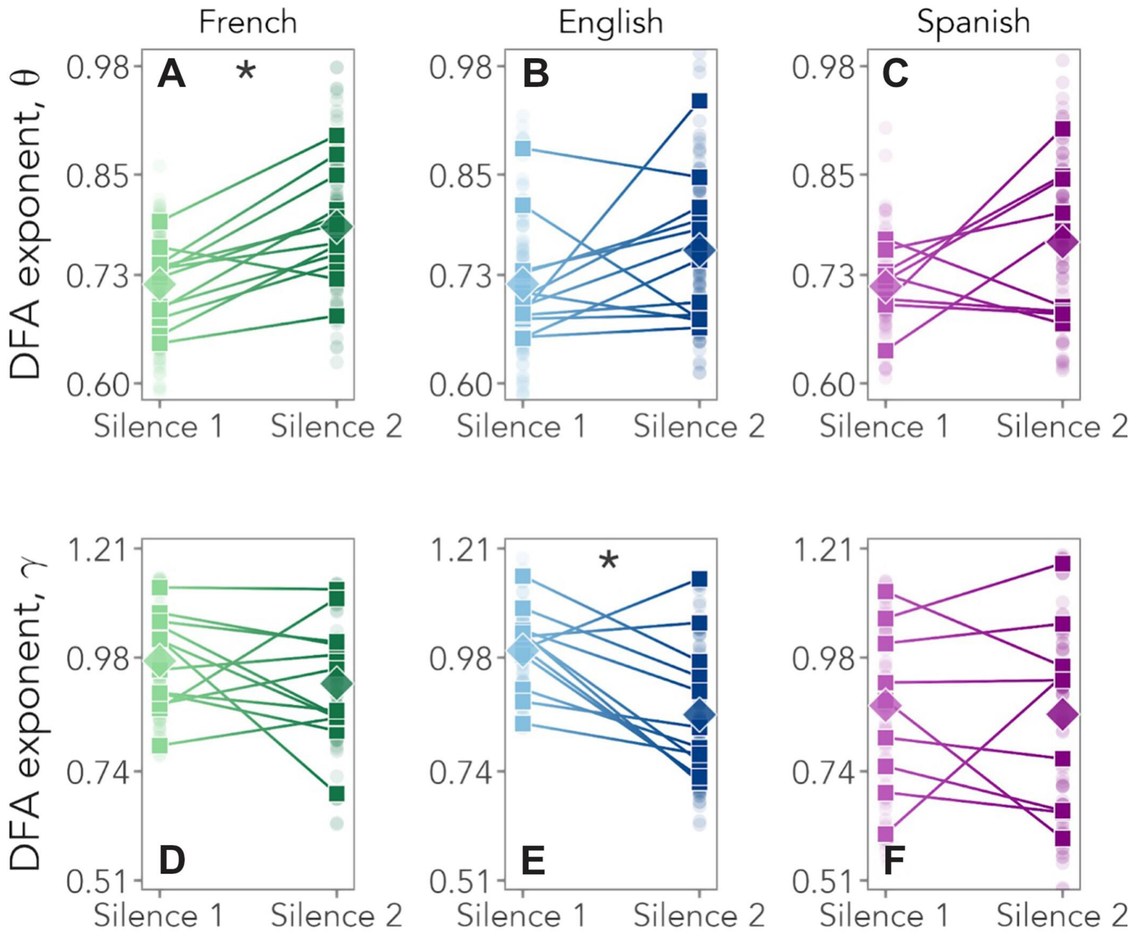
3) In **theta**, scaling exponents showed a statistically significant **increase** from silence 1 (α = 0.76 ± 0.06) to silence 2 (α = 0.81 ± 0.08; slope = 0.05, *P* = 0.0005) (table S2). in gamma, a significant decrease was observed (silence 1: α = 0.95 ± 0.1269; silence 2: α = 0.88 ± 0.16; slope = −0.07, *P* = 0.01)



Results 2: the role of prenatal experience directly

1) Linear mixed-effects model with Resting State Period (silence 1/silence 2) as a fixed factor and Participants as a random factor: in the theta band, **only infants who listened to French** last showed a significant increase in scaling exponents from silence 1 (α = 0.76 ± 0.05) to silence 2 (α = 0.82 ± 0.07; slope = 0.065, *P* = 0.0003). Not for Spanish or English

2) In the gamma band a significant decrease from silence 1 (α = 0.99 ± 0.08) to silence 2 (α = 0.86 ± 0.14) was found for those exposed last to English (slope = −0.14, *P* = 0.003). Not for French and Spanish



Conclusions

1) Newborns' electrophysiological activity has **positively correlated memory**

2) Exposure to speech rapidly **increases long-range correlations** in neural activity, thereby highlighting how language experience may shape the brain (language learning)

3) This facilitatory effect is specifically **present for the language and the frequency band (in utero) experienced prenatally.**

Together, these results provide the most compelling evidence to date that language experience already shapes the functional organization of the infant brain, even before birth.

Mariani B., ..., Gervain J., Science Advances, Vol 9, Issue 47, November 2023

Thanks to

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Thank you for your attention!