A "two peak" frequency pattern observed during the analysis of a Black ghost knifefish electric signal

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Introduction

Weakly electric fish are known to emit high frequency electric signals that allow them to navigate, communicate, and detect objects or prey in murky waters using an electric organ discharge (EOD).

The EOD originates from the superposition of action potentials produced by thin neuron-like electrocytes organized in rows and columns.

This clock-like signal is the least variable of any known biological oscillator, but the mechanisms underlying this extreme precision are not clear.

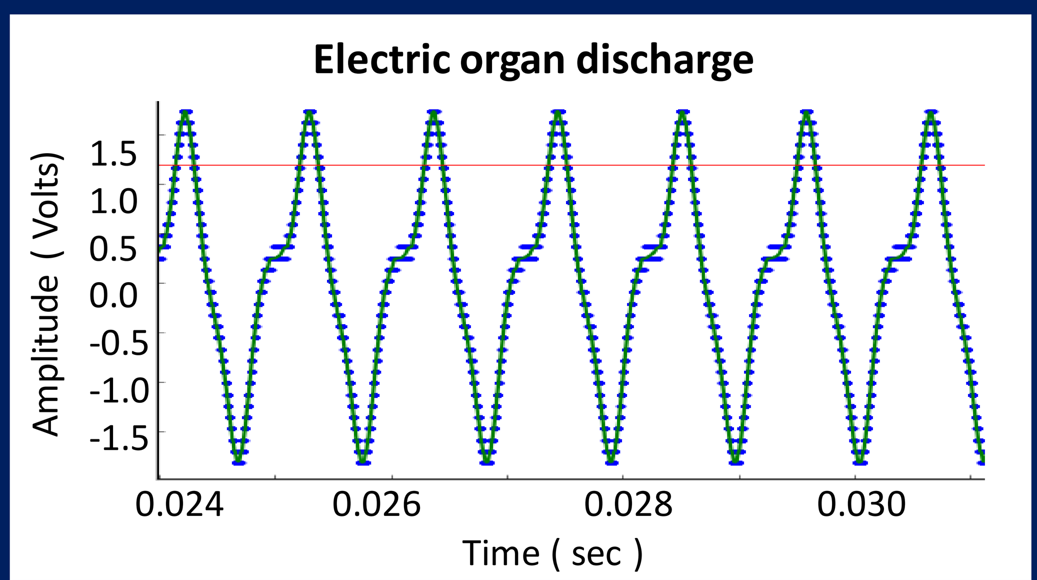
This study focuses on the characterization of this electric signal. The electric organ represents a model system allowing insight into the generation and control of brain oscillations in general.

Methodology

- **Experimental**: We measure the electric signal with two electrodes at the head and tail.

The signal is amplified to 2V, band-pass filtered (300Hz-5000Hz; AM Systems Differential Amplifier) and recorded with a Picoscope 3205D every 25 nanoseconds, to get a sampling frequency of 40MHz

(3 orders of magnitude better than any other standard protocol).

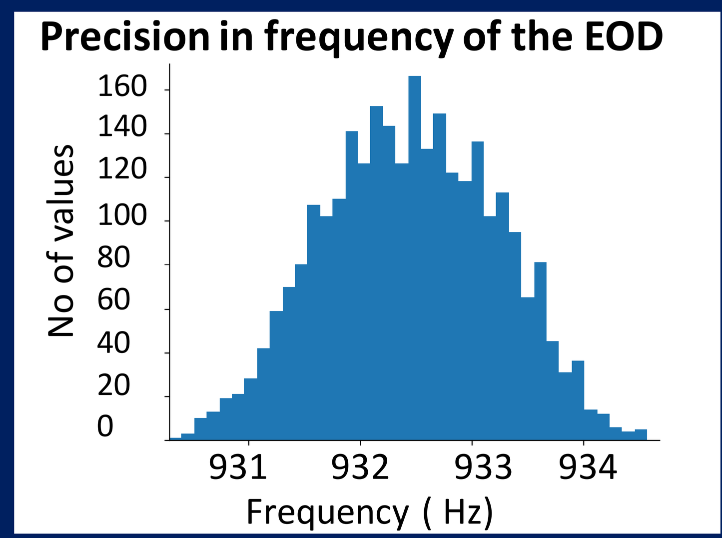


- **Analysis:** We used three different approaches to analyse cycle-to-cycle variability: the first involved a simple signal threshold; the second was based on the signal envelope using Hilbert transforms; and the third, used the phase of the Hilbert transform, giving more rigorous but similar results.

Results

- **Precision:**

The EOD precision can be quantified by the coefficient of variation (cv= standard deviation / mean). Previous studies (1) have shown incredibly low values for cvs. Here, the histogram in the figure shows the distribution of the frequencies over approximately 3000 cycles with a cv of (8.2×10^{-4}, compare to the typical human heart rate variability of 10^{-2}).

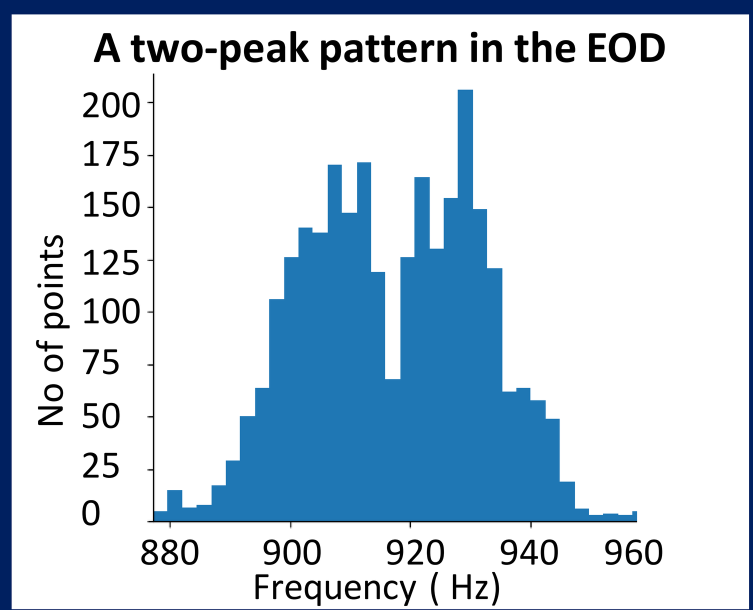


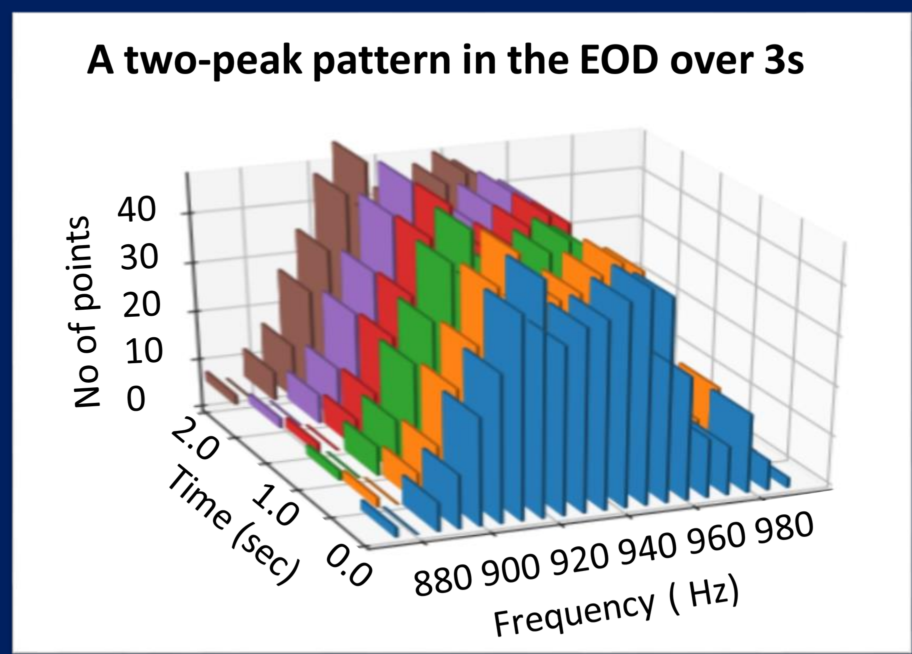
- **The "Two peak" pattern:**

One important observation was that under certain conditions, the histogram of frequencies exhibits two peaks. This suggests the possible existence of two frequencies with a difference of up to 30 Hz, significant compared to how stable the frequency is normally.

We hypothesize that the electric organs on the left and right sides of the fish are independent oscillators that normally are synchronized but can become transiently de-coupled.

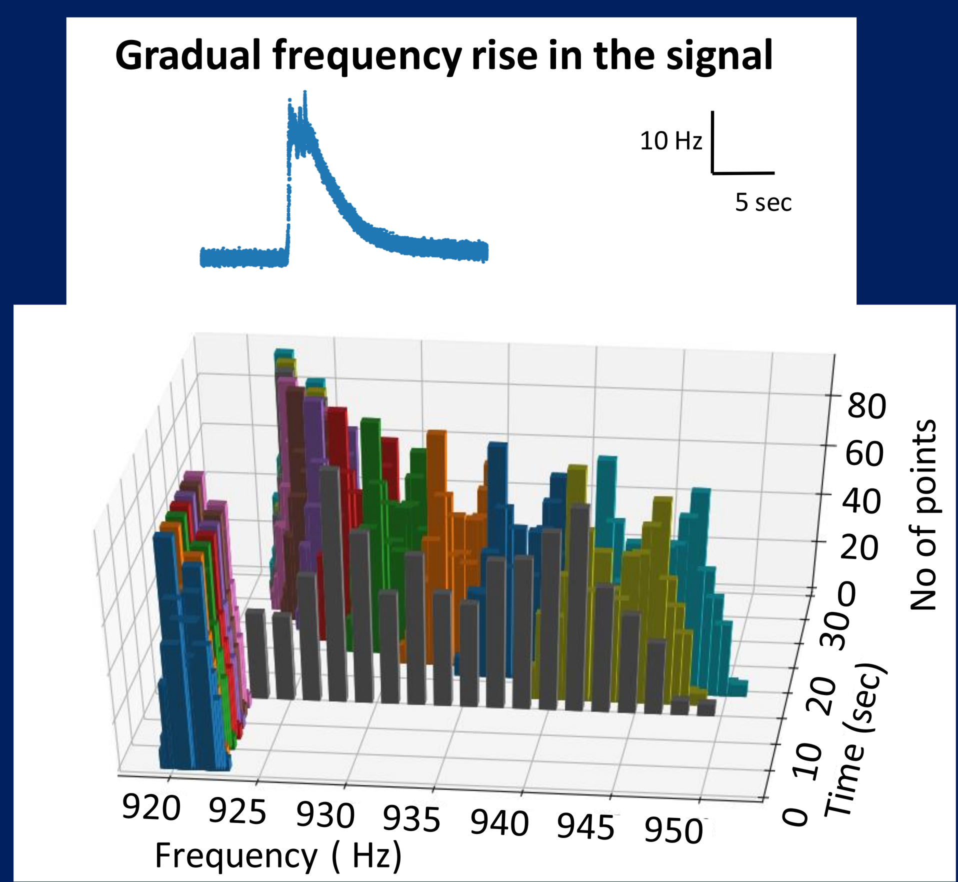
We have also looked at how this pattern behaves over time, to characterize these signals in more details. In some cases, an apparent two-peak pattern resulted from a stereotyped modulation of EOD frequency over time (see below). However, in other cases, this two-peak pattern was observed on much shorter time scales, consistent with a decoupling of the electric organ.





- **Other variability:**

Another unusual observation was the spontaneous rise in frequency followed by a quick return to normal levels within few seconds. This behaviour could be associated with communication signals called "gradual frequency rises" or GFRs (2). They represent an interesting source of information about how the fish interacts with its environment.



What is next ?

The two peak pattern provides an evidence of a transient de-coupling of two oscillators (right and left electric organs) This could be due to an overdriving stimulus from the brain, but there is still work going on to test it in more efficient ways.

These surprising aspects of the EOD such as its precision but variability at the same time may shine new light on the generation of high-frequency electric signals leading to a better understanding of brain oscillations in living systems.

References

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(2) Serrano-Fernández P. Gradual frequency rises in interacting black ghost knifefish, Apteronotus albifrons Journal of Comparative Physiology A, 89 (2003), pp. 685–692

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