Complex frequency modulations in freely interacting electric fish, *Apteronotus leptorhynchus*, recorded in their natural habitat

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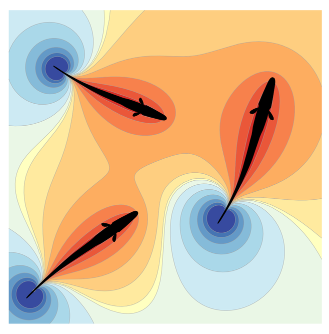
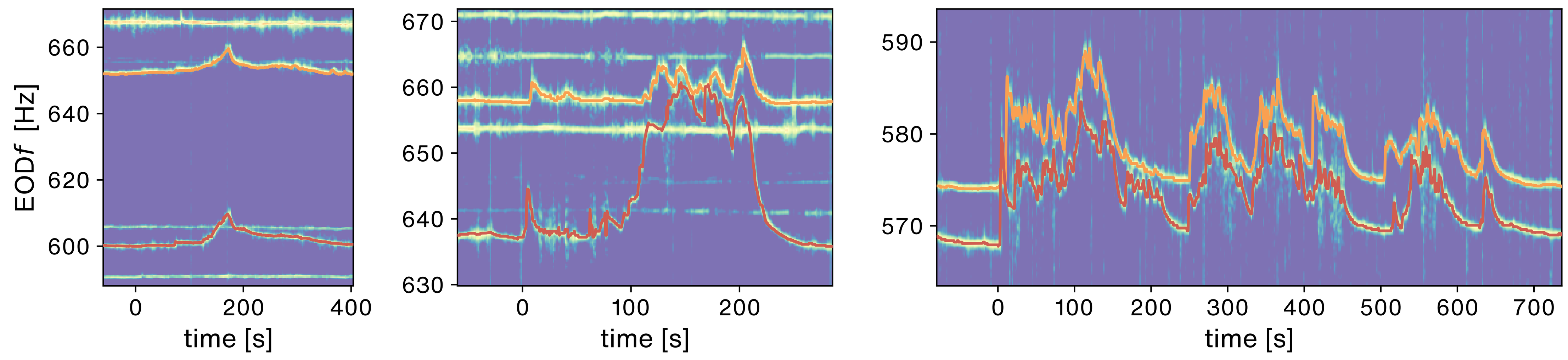


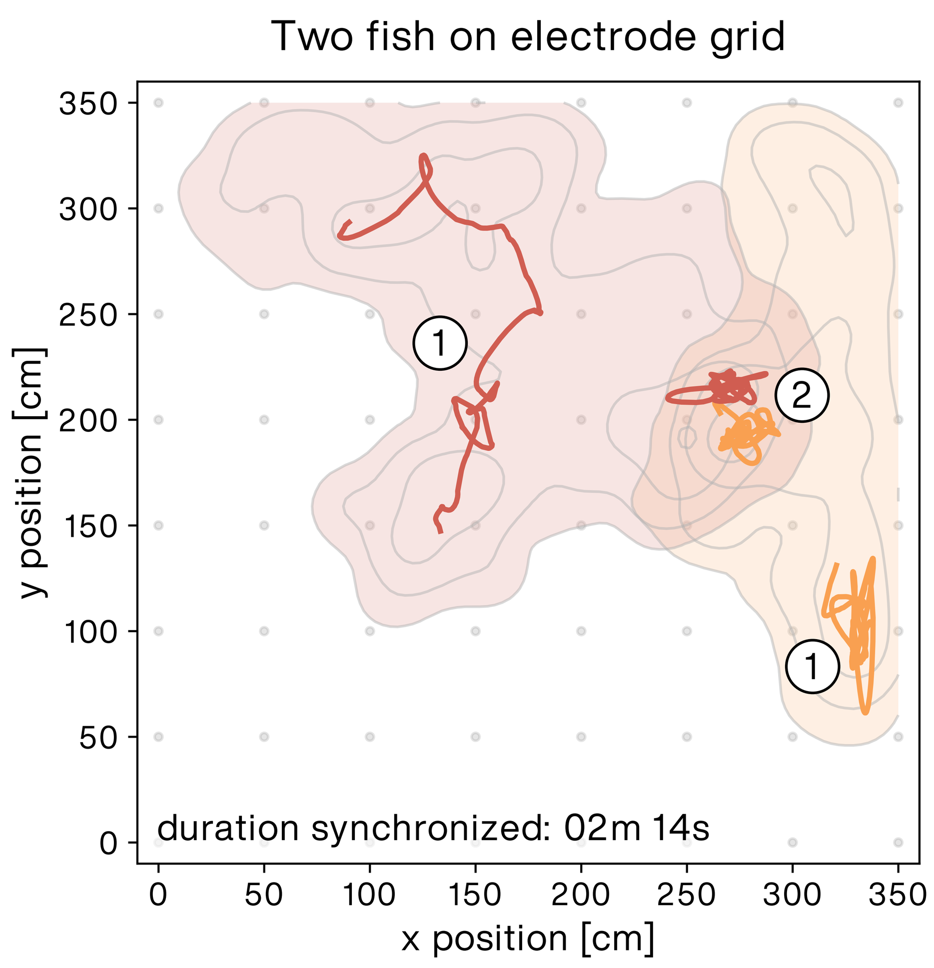
Introduction

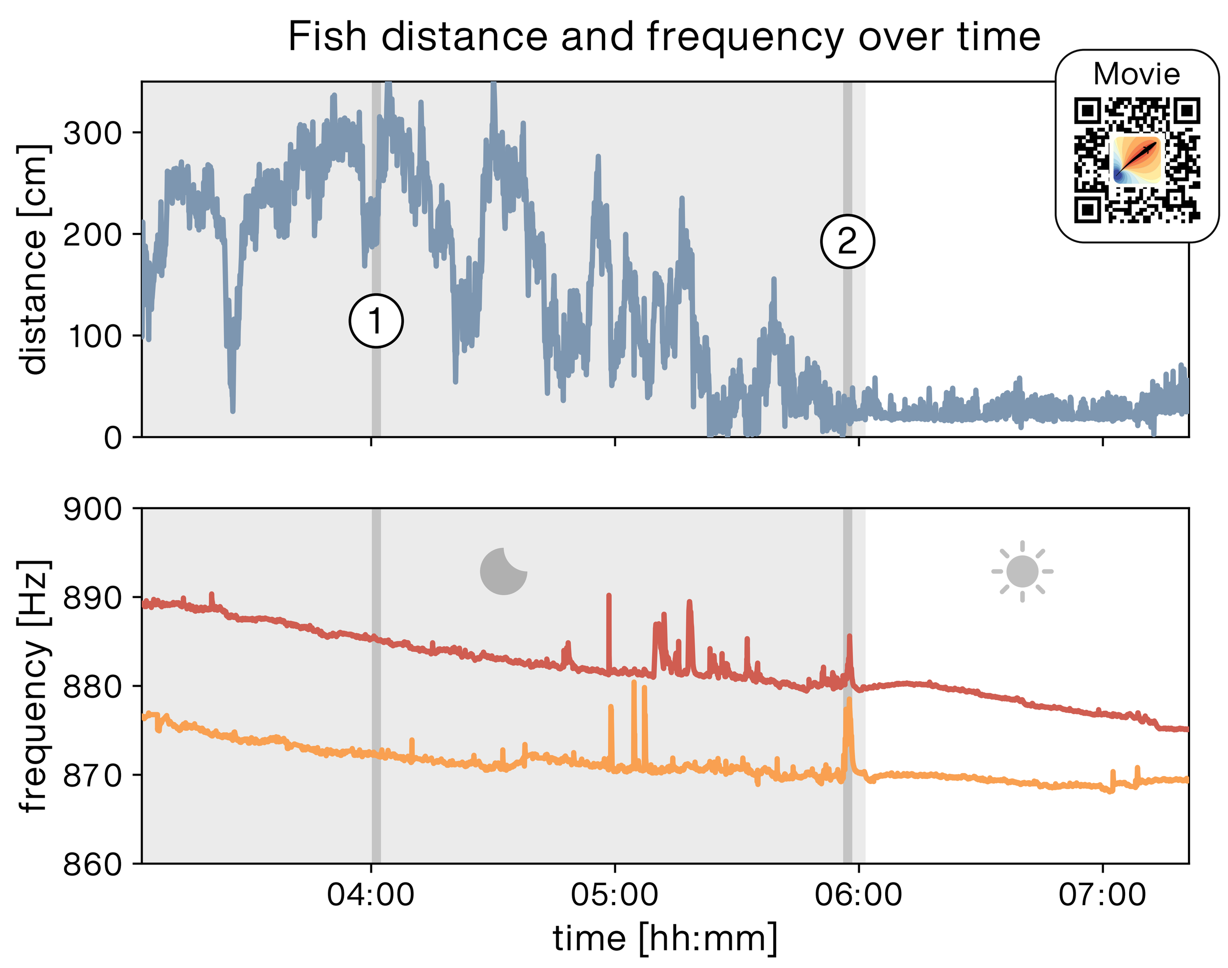
Weakly electric fish use their electric organ discharge (EOD) for navigation, foraging and **communication**. Signals associated with communication (chirps and rises) are extensively studied and can be identified by their stereotyped EOD frequency (EODf) modulations. But signals that are not as stereotyped receive little attention. For a **natural population** of *A. leptorhynchus*, recorded using an array of 64 electrodes, we find **synchronous** EODf modulations lasting many minutes. We designed a simple algorithm to detect synchronous modulations in two animals and analyzed their movements during frequency interactions.

Detected modulations

We found phases of synchrony up to 50 Hz in ΔEODf that lasted for over 10 minutes. Synchronous modulations ranged from clearly distinguishable and steep rises to smooth modulations with low EODf increases.





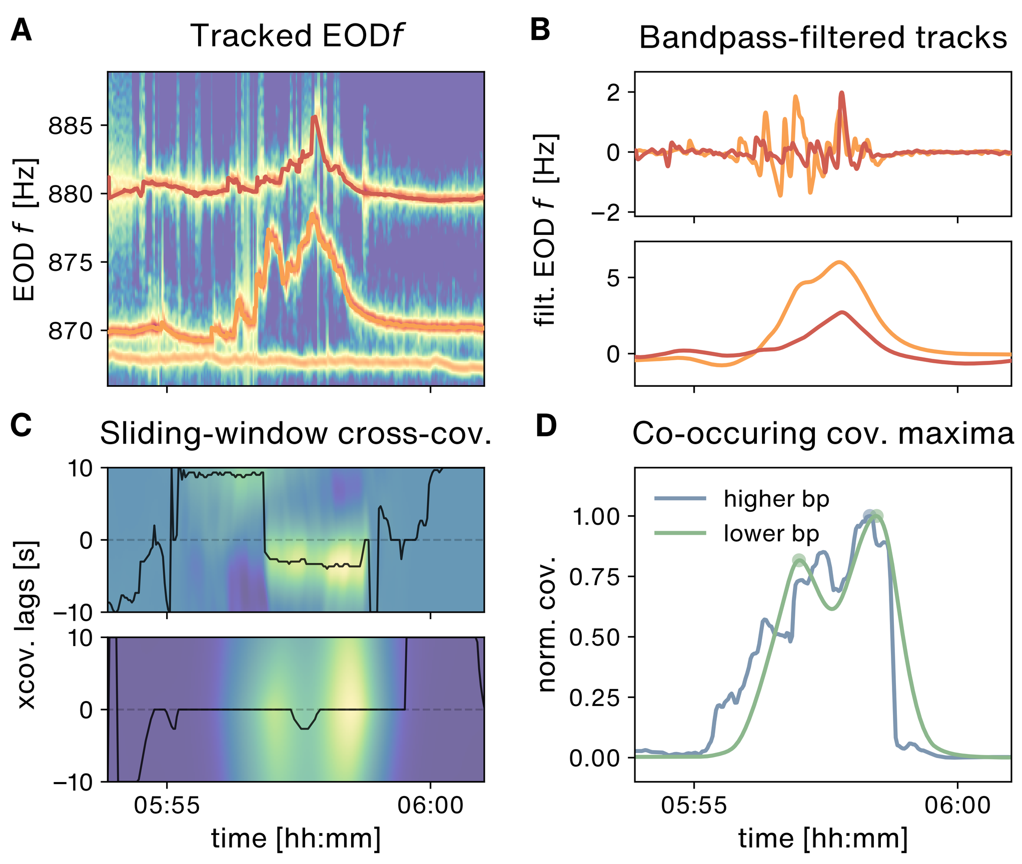


Event detection

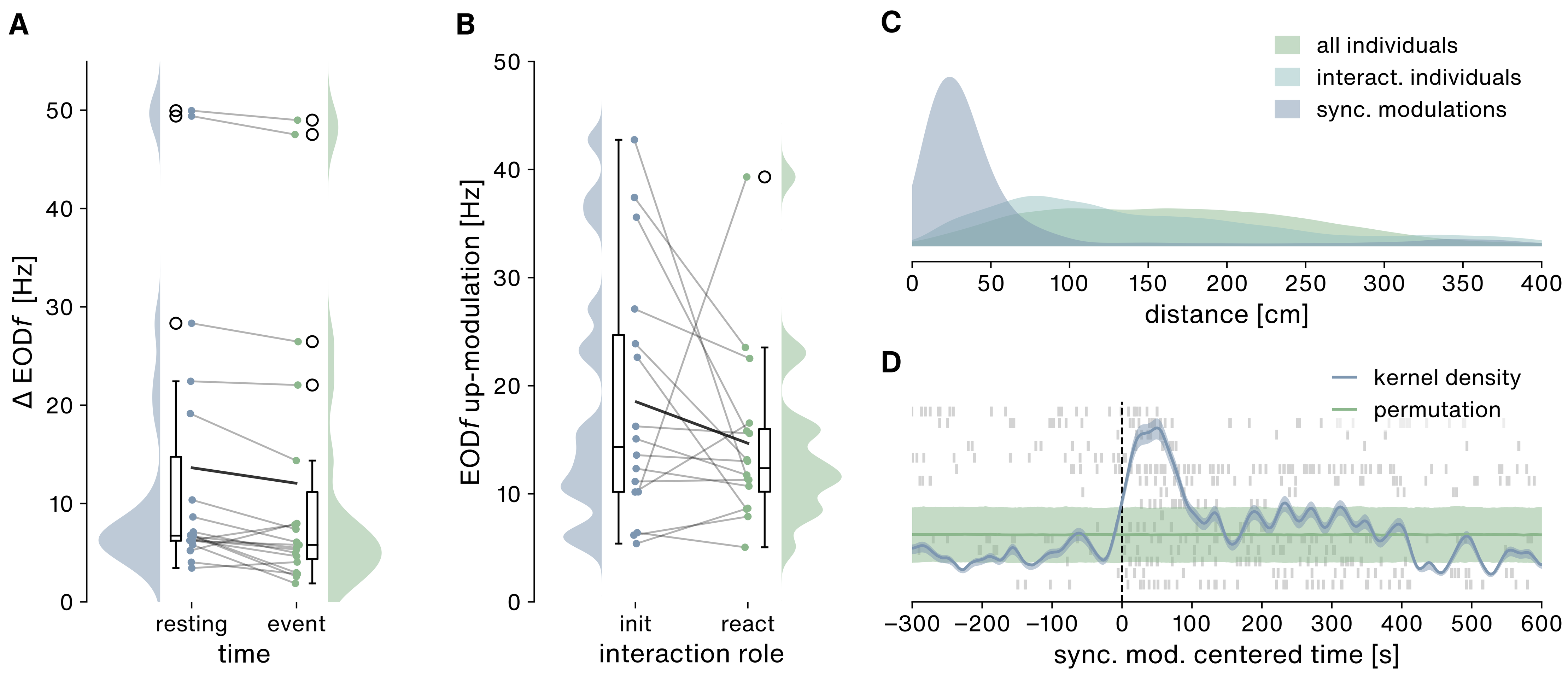
Detection of synchrony:

1. Extract pairwise EODf tracks (**A**).
2. Bandpass-filter on two time scales (**B**).
3. **Sliding-window cross-covariances** of filtered track-pairs, extract maxima across all lags (black line, **C**).
4. Detect peaks in covariances. Simultaneously co-occurring covariance peaks are "events" (**D**).
5. Manual validation of detected synchronous modulations using a minimalist GUI.

Detection of physical interactions using proximity, velocity and relative angle of heading trajectories between fish.



Interactions at modulations



- ΔEODf does not appear to decrease during synchronous modulations (**A**).
- Individuals that rise their EODf first appear to rise their frequency higher compared to reactors (**B**).
- Synchronized fish keep distances below 1 m (**C**) but distances over 3 m also occur (see **movie**).
- Spatial interactions increase **after** the start of a synchronous modulation (**D**).

Conclusion

- Our analysis is the first to indicate that *A. leptorhynchus* uses long, diffuse and synchronized EODf signals to communicate in addition to chirps and rises.
- The recorded fish do not exhibit jamming avoidance behavior while close during synchronous modulations.
- Synchronous signals **initiate** spatio-temporal interactions.

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