Electric Eels Elicit Egregious Escape Elimination

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You, too, can do SCIENCE!

- If you have a high-speed camera, an oscilloscope, an electrostimulator, and some fish.
- Oh, yes, and electric eels.

Today we examine “The Shocking Predatory Strike of the Electric Eel,” Kenneth Catania, *Science* (2014). (Cover article!)

Background

- Electric Eels (*Electrophorus electricus*, not actually eels, as it turns out) live in the Amazon and Orinoco river basins.
- Often hunt and attack prey in poor visibility, or when the prey is visually hidden.
- Can emit electric pulses which play a part in both search and attack.
- How do these pulses affect the prey, and how is this useful to the eel?

Hunting behavior

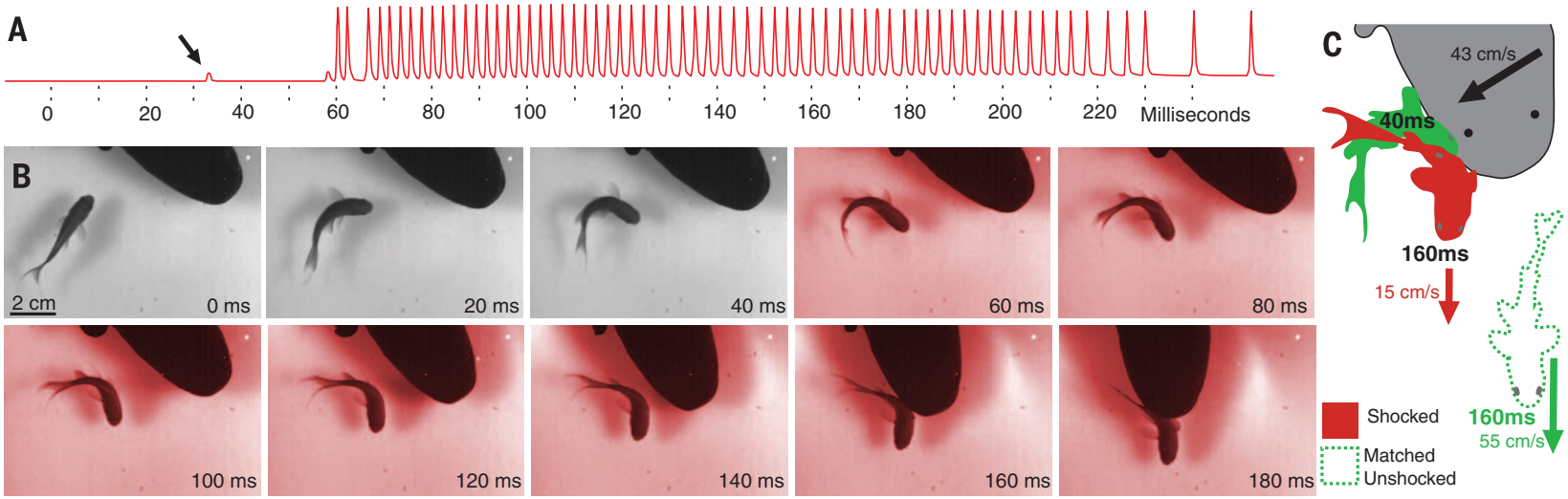


Fig. 1. Eel's discharge and strike. (**A**) Electric organ discharge corresponding to plates below. Arrow indicates low-amplitude discharge. (**B**) Video frames showing that fish movement is arrested by discharge. Red frames indicate electric organ discharge (movie S1). (**C**) The utility of the discharge illustrated. Shown are the prey fish at 40 ms (green) and later, the position and velocity of the eel and fish at 160 ms (red fish). Green dotted fish outline shows velocity and location of uninterrupted escaping fish matched in time, size, and position from 40 ms, suggesting that the eel would have missed without the discharge.

Supplemental video 1

TLD(L)

- It turns out that the (full-power) pulses elicit muscle contractions which can
  - Betray the position of the prey (doublets)
  - Reach tetanus, such that the prey cannot evade the eel's strike (full, 400Hz attack volley).
- The paper reports the experiments which show this.

Some *E. electricus* Anatomy

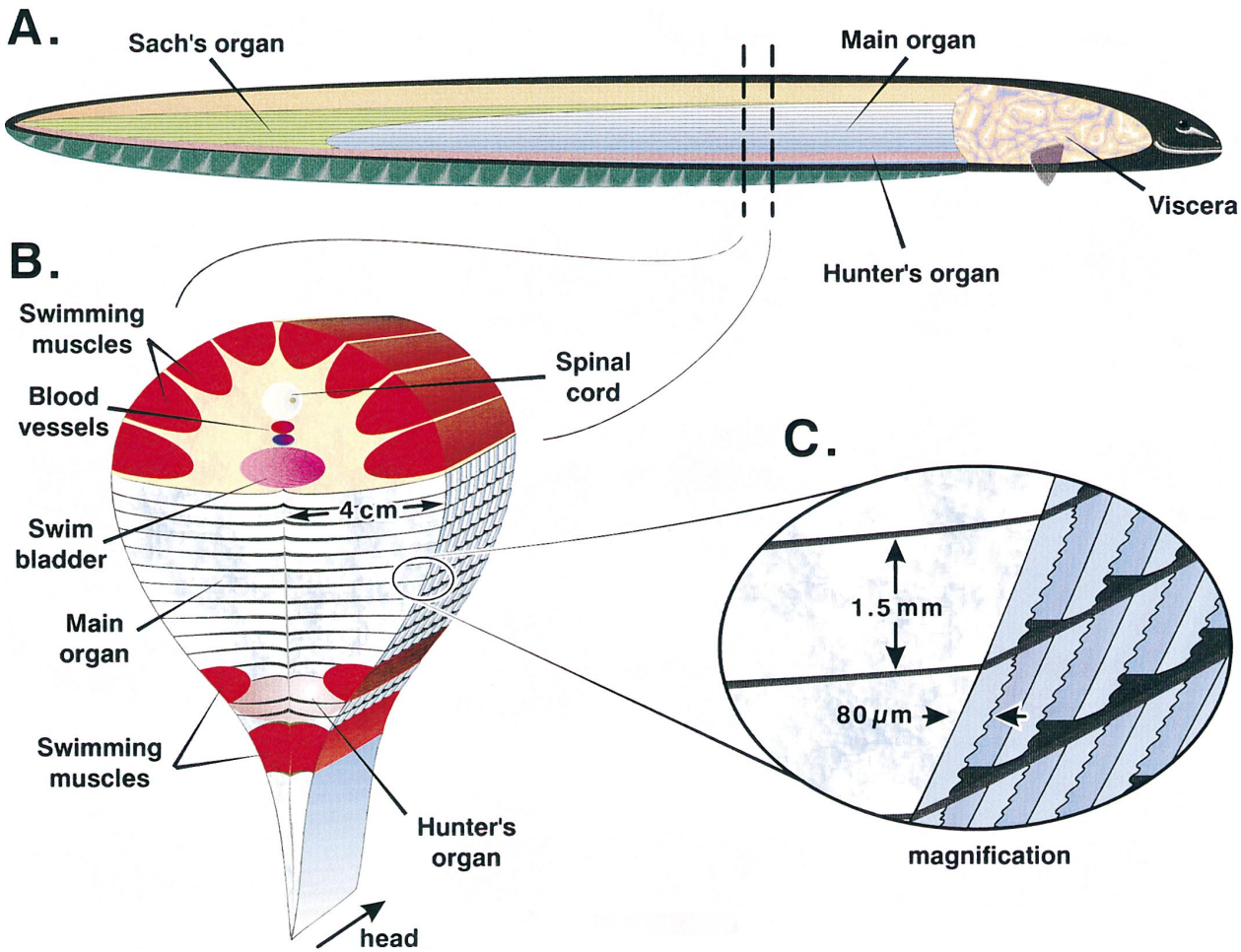
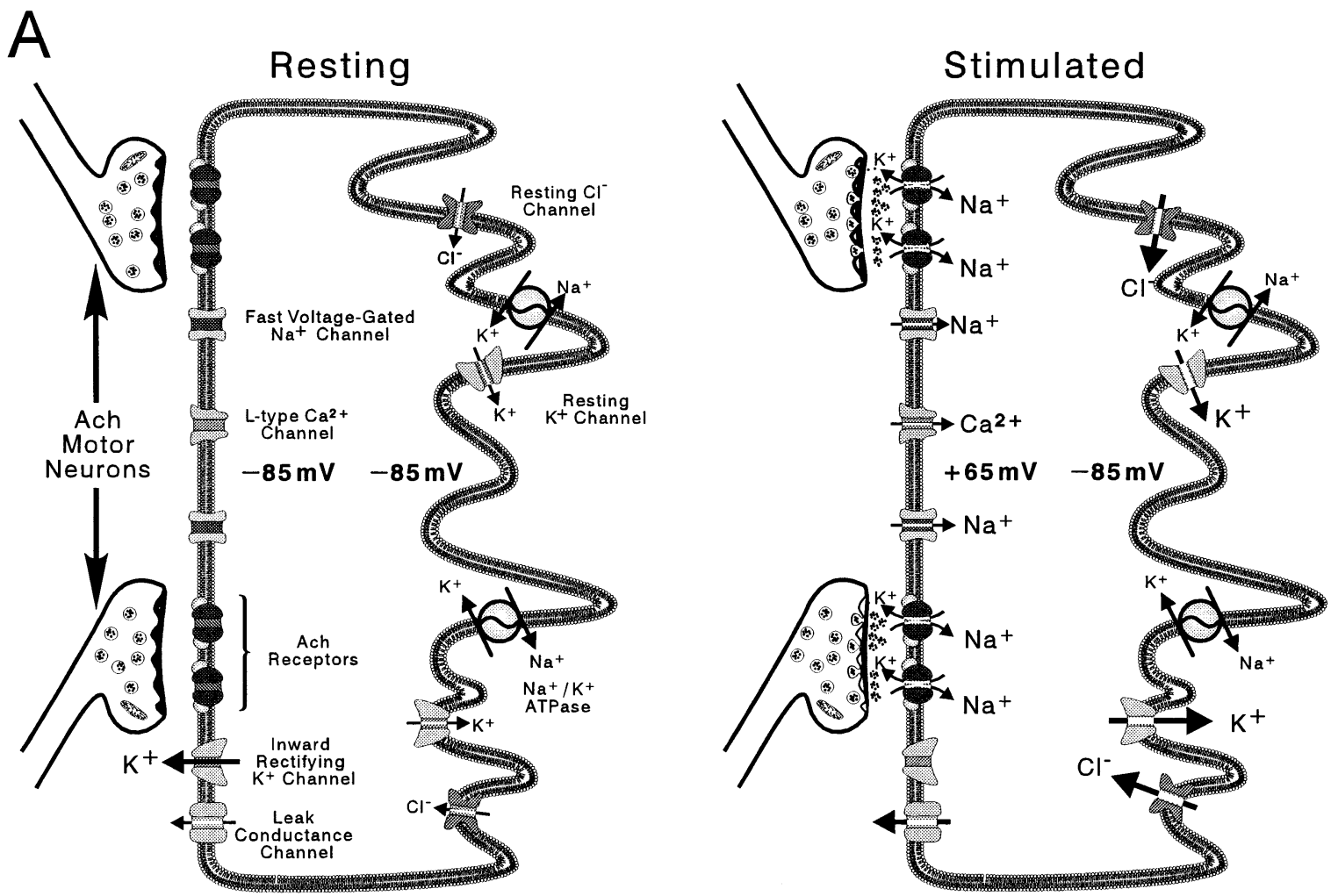


FIG. 1. Anatomy of the electric eel. (A) Diagram illustrating the anatomical orientation of electric organs. (B) A section through the middle portion of the eel, drawn such that the anterior surface is nearest the reader. (C) Columns of electrocytes extend the length of the electric organ. In this panel, the flatter, posterior surface of each electrocyte would be innervated by numerous electromotor neurons (not shown). Heavy dark horizontal lines depict insulating septa delineating columns of electrocytes. Light blue shading represents the interior of electrocytes exposed in the cross-section.

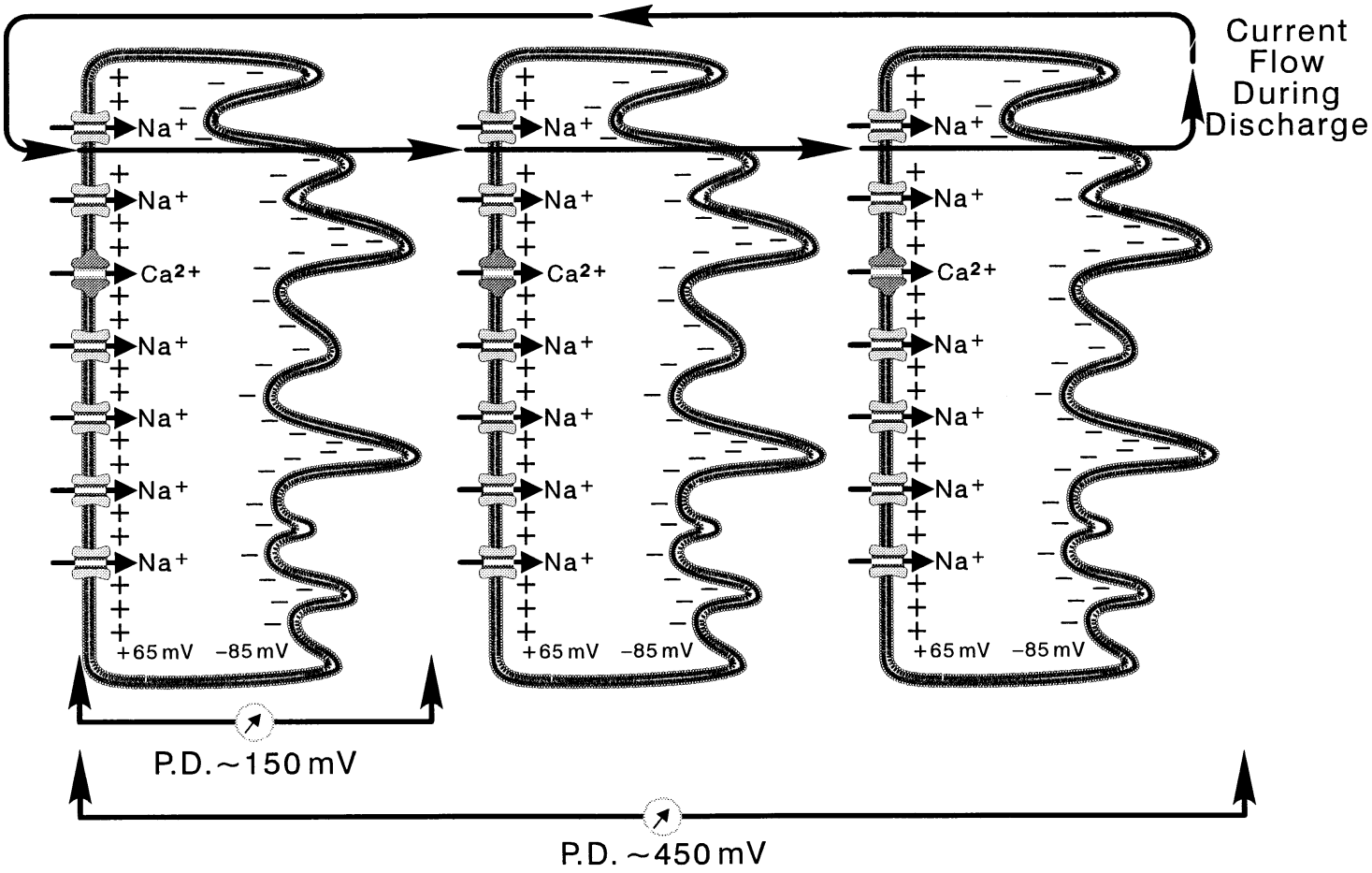
Gotter et al., "*Electrophorus electricus* as a model system for the study of membrane excitability." *Comp. Biochem. Physiol.*, 1998.

Electrocytes



From Gotter et al., 1998.

Electrocytes II



From Gotter et al., 1998.

Stack ≈4000 such cells: 4000×150 mV $= 600$ V ! Stacks in parallel: current delivery.

How does the attack volley immobilize prey?

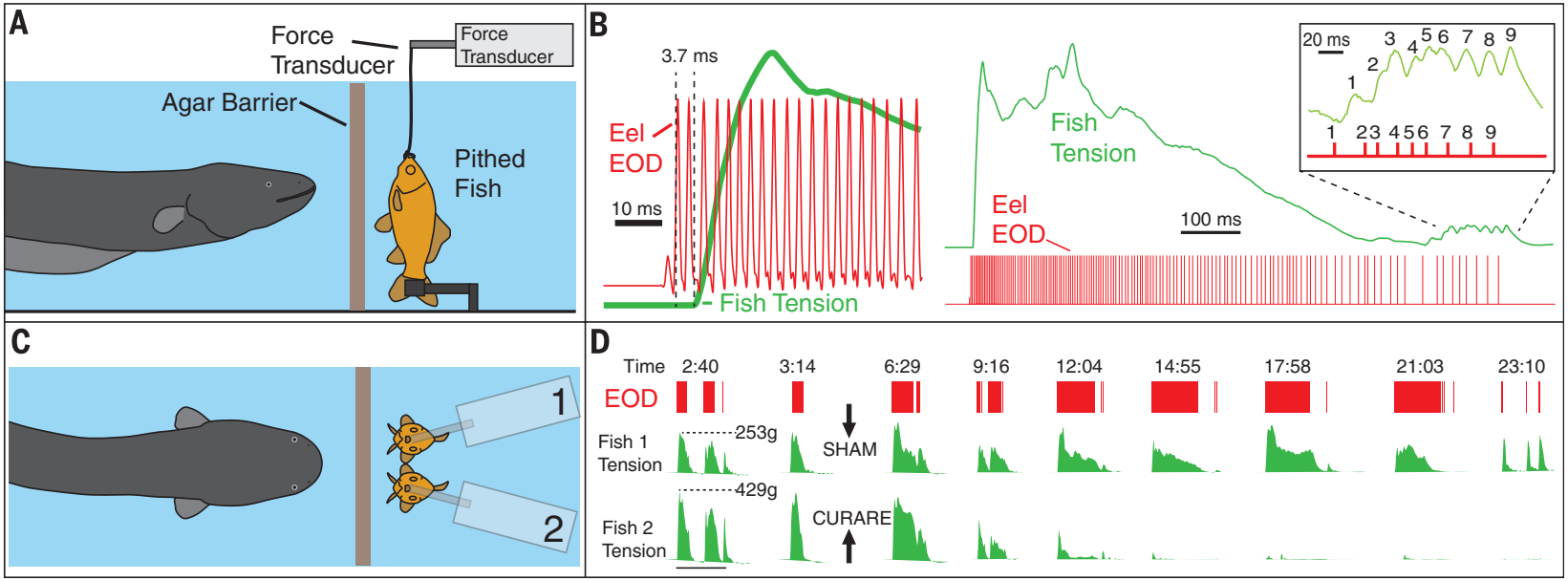


Fig. 2. Paradigm for investigating strong electric organ discharge. (**A**) An agar barrier separated eels from pithed fish. Eels shocked earthworms while fish tension was recorded. (**B**) All eels induced whole-body tension, occurring 2 to 4 ms after strong discharge onset. No tension was developed from weak discharge. At low frequencies, individual twitches emerged for each discharge (top right) (fig. S2). (**C**) Two pithed fish (fish 1, 19 g; fish 2, 21 g) preparation. (**D**) Effect of curare. Red trace indicates strong electric organ discharge matched in time to unnormalized fish tension (green). Arrows indicate time of injections (fig. S3). Bar in (D) = 500 ms.

The attack volley:

- Triggers a massive (tetanic) response in prey
- Works via a mechanism which is:
  - dependent on ACh / NMJ function.
  - not dependent on intact brain or spinal cord.

This suggests that the attack volley remotely activates motor neuron efferents in the prey.
Catania argues that the particular timing of the attack volley's constituent pulses may have been selected to most efficiently induce rapid muscle tension.

What are the doublets for?

- “Doublets” are pairs of full-power pulses which are emitted during search, and often immediately before attack volley.
- Hypothesis: doublets play a role in finding hidden prey or confirming that potential prey are of interest.

Doublets precede attacks on hidden prey

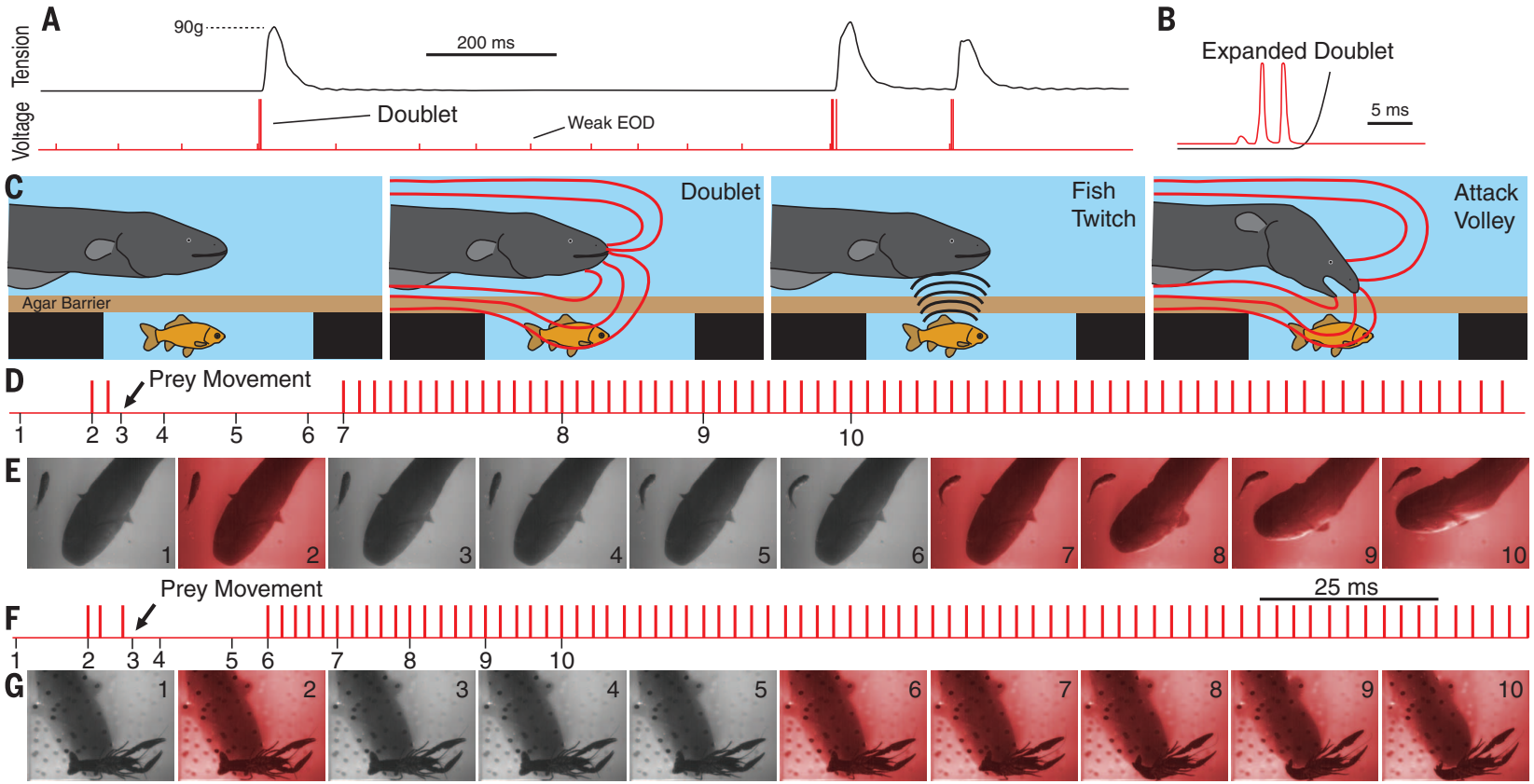
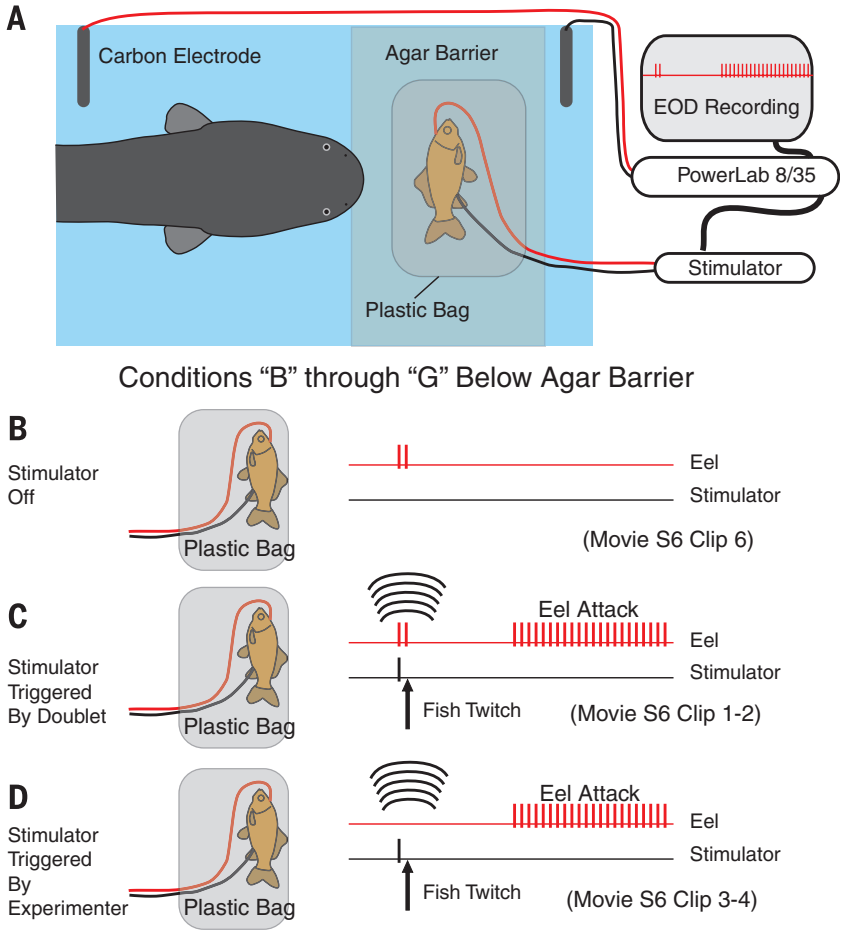


Fig. 3. Doublets during hunting. (**A**) Examples of doublets and corresponding tension responses. (**B**) Expansion of the first doublet and corresponding tension trace (off-scale peaks were estimated). (**C**) Schematic of attack sequence. (**D**) Example of high-voltage electric organ discharge for an attack preceded by a doublet. (**E**) Video frames from volley shown in (D). Numbers correspond to numbers in (D). (**F**) Timing of the high-voltage discharge for attack preceded by a triplet. (**G**) Video frames for volley shown in (F).

Supplemental video 5

The doublet (triplet) seems to elicit a strong muscle contraction, which in turn triggers the eel's attack.

Doublet Mechanism



So the doublet attack pattern is:

1. The eel emits a doublet, interrogating the prey; if live prey,
2. This triggers a muscular response
3. Prey movement moves the water; upon detecting the vibration,
4. The eel starts an attack volley and strike.

Electric eels are awesome

There are interesting questions to be answered (and *Science* publications to be obtained!) with simple methods.
And electric eels.