Mechanisms of *Paramecium* tube escape learning

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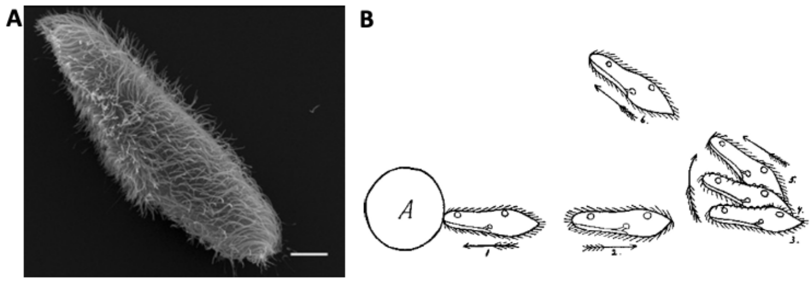
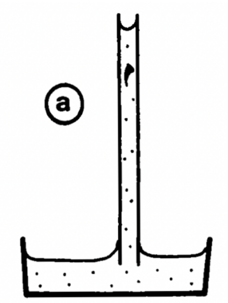
Paramecium is a unicellular organism that swims in fresh water by beating thousands of cilia. When it is stimulated (mechanically, chemically, optically, thermally…), it often swims backward then turns and swims forward again. This "avoiding reaction" is triggered by a calcium-based action potential. For this reason, some authors have called *Paramecium* a "swimming neuron" (Brette, 2021). This project belongs to a broader project aiming at developing integrative models of *Paramecium*, bridging physiology and behavior. This is a collaborative effort between the labs of Romain Brette (neuroscience, Vision Institute), Alexis Prevost et Laetitia Pontani (physics, Laboratoire Jean Perrin) and Eric Meyer (genetics, Ecole Normale Supérieure), in Paris. The team has already developed experimental techniques (behavior and electrophysiology), including a device to immobilize *Paramecium* for electrophysiology experiments (Kulkarni et al., 2020), and a basic biophysical model of the action potential and electromotor coupling.



A, Scanning electron microscopy image of Paramecium tetraurelia (scale bar: 10 µm) (Valentine et al., 2012). B, Avoiding reaction against an obstacle, as illustrated by Jennings (Jennings, 1906).

This project aims at understanding tube escape learning, first describe by French in 1940 (French, 1940). A single *Paramecium* is placed in a drop and a thin tube is lowered into it. The organism is drawn into the tube by capillarity. It then escapes from the bottom after about 30 s. When the experiment is repeated, escape time decreases to around 15 s after a few trials. According to French, after the initial trials, paramecia go and back and forth in the tube only a few times then take "one long dive to the bottom". Studies of tube escape learning in *Stentor*, another ciliate, suggest that the phenomenon is related to gravitaxis (Bennett and Francis, 1972; Hinkle and Wood, 1994). Performance improvement is seen only when the tube is vertical, not when it is horizontal, where escape is fast from the first trial. This suggests the following (speculative) explanation: in a vertical tube, paramecia are trapped near the top because of negative gravitaxis, then prolonged confinement inhibits the normal gravitactic behavior, so that the organism can escape to the bottom.



Experimental setup in Stentor (Bennett and Francis, 1972).

The goal of the project is to understand the basis of tube escape learning, and in particular to test whether it is related to a modulation of gravitaxis. The first step of the project is to reproduce the basic experiment, and the experiment with a horizontal tube. The trajectories will be filmed and analyzed in detail, similarly to previous studies of gravitaxis (Roberts, 2010). The student will then measure trajectories in the vertical dimension before and after tube escape; in particular: is there a switch in gravitactic behavior, or in other aspects of behavior? if so, does the switch depend on the number of contacts with the meniscus? Finally, the student will explore whether the phenomenon can be reproduced by electrical stimulation.

The project can be adapted to the duration of the project and the profile of the student.

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