Magnetic Fields Create Artificial Gravity Chamber for Microorganisms

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Methods to simulate variable strength gravity environments appeal to biologists and physicists researching how single biological cells are able to sense and transduce the very weak forces of gravity. Our simulation approach employs magnetic forces that can be directed to pull in tandem with gravity's forces to create enhanced gravity or to push in opposition to gravity to create weakened and even inverted gravity (Fig. 1). These strong magnetic forces are generated by intense inhomogeneous magnetic fields such as those available at the National High Magnetic Field Laboratory acting on the diamagnetic materials naturally present in cells. The direction and the magnitude of the magnetic forces are easily controllable.

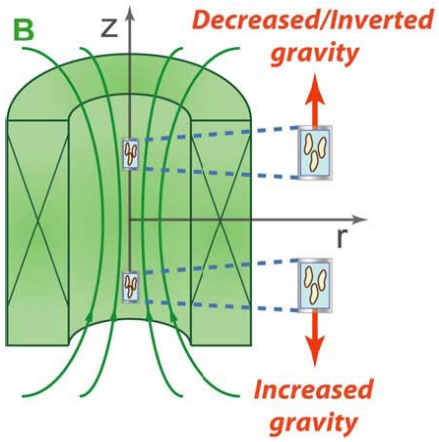

Figure 1. Schematic of the cross section of a magnet. Increased and decreased gravity environments can be achieved by simply changing the location of the cell sample within the magnet. The intensity of the force is controlled by the magnetic field strength, the magnetic properties of the cell and the solution in which they swim.

The single cell ciliate, *Paramecium caudatum*, exhibits a gravi-sensing ability known as *gravikinesis*. It actively regulates its swimming speed depending on whether it swims with or against the force of gravity. The regulation is always aimed to fight its natural tendency to sediment so that it swims harder upward than downward.

We have successfully observed and quantified *gravikinesis* in *Paramecium* using the magnetic force gravity simulation technique. Besides reproducing results obtained in the high gravity of a centrifuge, our studies also revealed an equivalent response to inverted simulated gravity that restricts possible models of how the organisms sense gravity's force. We also succeeded in stalling the swimming paramecia and hence have measured their maximum propulsion force. We should note that homogenous magnetic fields do not induce any swimming

speed changes in paramecia, therefore our observations are genuinely a response to the simulated gravity and not a side effect of magnetic fields.

This gravity simulation technique can be applied to a wide range of swimming microorganisms and living immobile cells. It is the only available earthbound technique that allows the investigator to apply the wide range of simulated gravities, from $g<1$ to $g>1$, to a single sample and thus, it eliminates the uncertainties arising from using different sample cells in low and high gravity experiments.