Cockroaches use wings and legs together to better self-right on the ground

Ratan Othayoth, Chen Li

Animals must self-right when flipped over on the ground, but this task is often strenuous. The discoid cockroach often attempts to somersault to self-right by pushing its wings against the ground, but this is rarely successful and leads to multiple attempts. When self-righting is eventually successful, the animal always rolls to the side after the initial pitching. Curiously, the animal often flails its legs vigorously during wing pushing. Here, we studied how wing opening and leg flailing together contribute to self-righting. We developed a robot with two wings and a laterally swinging leg and control the robot's wing opening and leg oscillation to emulate the animal's strenuous self-righting. As wing opening and leg oscillation amplitudes increased, self-righting probability increased and the number of attempts required for self-righting decreased. To understand physical principles, we developed a potential energy landscape model to measure potential energy barriers to self-right and compared them to kinetic energy fluctuation for both pitching and rolling motions. Without leg perturbation, pitching kinetic energy from wing propulsion was insufficient to overcome the high potential energy barrier to somersault. However, wing opening lowered the smaller potential energy barrier to self-right by rolling and allowed kinetic energy fluctuation from leg perturbation to probabilistically induce barrier-crossing and lead to self-righting. These results demonstrated that variation in movement can lead to stochastic outcomes and is advantageous when locomotor behavior is split into distinct modes. Our potential energy landscape revealed how stereotyped self-righting behavior is constrained by and emerges from physical interaction.