How cockroaches adjust body and legs to traverse cluttered beam obstacles

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Animals transition between diverse locomotor modes to traverse complex 3-D terrain with many large obstacles. For example, to traverse grass-like beam obstacles, a discoid cockroach can transition from pitching its body against the beams (the pitch mode) to push across to rolling into a gap between beams (the roll mode). By contrast, mechanistic understanding of terrestrial locomotion is largely focused on how to generate or stabilize near-steady-state, limit-cycle behaviors such as walking and running. Here, we quantified how the cockroach adjust its body and appendages to make the pitch-to-roll transition (N = 3 individuals, n = 36 trials). First, the animal used its hind legs differentially, extending one while retracting the other (10 ± 3 mm difference in body-tarsus distance between left and right hind legs), presumably to generate a rolling torque. Second, the animal tucked both hind legs inward (sprawl angle between two hind legs reduced by ~18° ± 19°), presumably to reduce roll stability. Third, the animal flexed its head repeatedly (standard deviation of head flexion = 9°). Fourth, after rolling into the gap, the animal used its hind legs to push the terrain to propel forward while flexing its abdomen (standard deviation of abdomen flexion = 9°). We modeled body-obstacle interaction using a potential energy landscape approach to evaluate whether head flexion makes transition easier. Finally, we are developing a robotic physical model that can flex its head and abdomen with underactuated body pitch and roll control, instrumented with force sensors, to further study sensory feedback control.