Coordination between wings and legs helps cockroach to self-right on the ground

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Animals and robots must right themselves after flipping over on the ground. The discoid cockroach can open its wings to push against the ground to try to somersault to self-right. However, because this maneuver is strenuous, the animal rarely succeeds in somersaulting, and often closing and opening its wings repeatedly for more attempts. In this process, it often flails its legs, which eventually perturbs the body to roll to the side to self-right. Here, we studied the effect of randomness in wing-leg coordination on self-righting performance using simulation and theoretical modeling. We observed that both wing and leg oscillations have large randomness compared to leg oscillation during walking and running. To test whether such large randomness is useful, we developed a multi-body dynamics simulation of a cockroach-inspired self-righting robot. The robot repeatedly opened and closed wings and oscillated an appendage mimicking flailing legs. Wing-leg coordination, measured by the phase between wing and leg oscillations, had a crucial impact on self-righting outcome. With randomness, the system explored phases thoroughly and had a better chance of encountering good phases that resulted in self-righting. Next, we elucidated why self-righting outcome depends sensitively on phase by creating a dynamical systems model of leg-body-wing-ground interaction. We used the model to calculate potential energy barrier, mechanical energy contribution by wing pushing and leg flailing, and mechanical energy dissipation due to collision. We discovered that phase affects self-righting by changing mechanical energy budget. Well-coordinated appendage motions (good phase) accumulate more mechanical energy than poorly-coordinated motions (bad phase).