Experimental studies suggest differences in thorax stiffness distribution between insects with synchronous and asynchronous indirect flight muscles

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Abstract

Recent studies have idealized the insect flight drive train as a system made up of two stiffness elements: a parallel element, representative of the flight muscles and exoskeleton, and a series element, representative of the wing hinge. However, it is not well understood if the relative stiffness of each of these elements differs across insect flight types. We hypothesized that insects with synchronous flight muscles (where there is a one-to-one correspondence between muscle action potential and wingbeat) have higher relative series stiffness compared to insects with asynchronous flight muscles (where there is a one-to-many correspondence between muscle actional potential and wingbeat), and that the series element experiences larger deformation in asynchronous fliers. We performed experimental studies to assess these hypotheses. First, we measured dorsal ventral thorax stiffness in six insect species using quasi-static force displacement testing. When accounting for insect size and weight, the asynchronous thorax was 3.8 times stiffer than the synchronous thorax, suggesting the relative stiffness of the series element in asynchronous insects is higher. Next, we simultaneously measured thorax deformation and the inertial/aerodynamic forces generated by the flapping wing during tethered flight of the same species. Compared to insects with synchronous musculature, insects with asynchronous muscle deformed their thorax 60% less relative to their thorax diameter, but their wings generated 2.8 times greater forces relative to their body weight. This suggests insects with asynchronous muscle experience larger inertial forces, which may contribute to increased deformation of the series element stiffness. Finally, to better understand wing hinge dynamics in asynchronous insects, we recorded wing rotation and thorax deformation in tethered bumble bees with intact and clipped wings. We found that wing clipping did not affect the amplitude of thorax deformation or wing rotation but did influence their relative phase, indicating a dynamic mapping between the two.

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