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Research paper

Biomechanics of the stick insect antenna: Damping properties and structural correlates of the cuticle

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ABSTRACT

The antenna of the Indian stick insect *Carausius morosus* is a highly specialized near-range sensory probe used to actively sample tactile cues about location, distance or shape of external objects in real time.

The length of the antenna's flagellum is 100 times the diameter at the base, making it a very delicate and slender structure. Like the rest of the insect body, it is covered by a protective exoskeletal cuticle, making it stiff enough to allow controlled, active, exploratory movements and hard enough to resist damage and wear. At the same time, it is highly flexible in response to contact forces, and returns rapidly to its straight posture without oscillations upon release of contact force. Which mechanical adaptations allow stick insects to unfold the remarkable combination of maintaining a sufficiently invariant shape between contacts and being sufficiently compliant during contact? What role does the cuticle play?

Our results show that, based on morphological differences, the flagellum can be divided into three zones, consisting of a tapered cone of stiff exocuticle lined by an inner wedge of compliant endocuticle. This inner wedge is thick at the antenna's base and thin at its distal half. The decay time constant after deflection, a measure that indicates strength of damping, is much longer at the base ($\tau > 25$ ms) than in the distal half ($\tau < 18$ ms) of the flagellum. Upon experimental desiccation, reducing mass and compliance of the endocuticle, the flagellum becomes under-damped. Analysing the frequency components indicates that the flagellum can be abstracted with the model of a double pendulum with springs and dampers in both joints.

We conclude that in the stick-insect antenna the cuticle properties described are structural correlates of damping, allowing for a straight posture in the instant of a new contact event, combined with a maximum of flexibility.

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