Second, 'selling' the importance of functional and phylogenetic diversity to the people on whose support MPA creation and success depend might be difficult, unless more research links these aspects of biodiversity to ecosystem services, which are readily understood and valued by people. Finally, it is becoming clear that the preservation of the many facets of biodiversity requires a scale of action that transcends political boundaries. Unfortunately, as we are seeing with climate change, regional and global interests still rarely trump national ones.

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Behavioral Neurobiology: The Bitter Life of Male Flies

Male fruit flies demonstrate aggression and even courtship towards other male flies. A new study reveals that these behaviors are induced via a bitter gustatory receptor.

Sweta Agrawal and Jeffrey A. Riffell

We have all experienced first-hand the intimate connection between smell and taste, whether it be drooling at the smell of a good meal or enduring eating with a stuffy nose. While the interaction of these two senses is immediately obvious in humans, little is known about if and how these senses interact in other animal species. A recent study by Wang *et al.* [1] strives to address this problem in the context of pheromonal control of male fly social behaviors.

In insects, smell and taste are both important senses regulating social behavior. Pheromones, chemical cues used to communicate between individuals of the same species, were first identified in insects more than sixty years ago [2]. Work on insect chemosensation has come a long way since, from determining the cellular and molecular mechanisms of the pheromone binding to the receptor [3,4], to how the information is processed in brain to drive behavior [5,6], to how those behaviors control interactions in the field [7]. Furthermore, similar mechanisms occur across diverse insect taxa — from Lepidoptera [8] to Hymenoptera [9] to Diptera [10] — demonstrating the general importance of chemosensory systems in social interactions.

The fruit fly *Drosophila melanogaster* is a particularly powerful model organism for studying the role of chemical communication between conspecifics. Aside from the suite of genetic tools available for these flies, they also exhibit a rich repertoire of robust social behaviors that are modulated by both heavy cuticular hydrocarbons (sensed via gustation [11,12]) and an air-borne pheromone *cis*-vaccenyl acetate (cVA; sensed via olfaction [13,14]) (Figure 1). Flies lacking all gustatory sensilla [15], cuticular hydrocarbons [16], or specific gustatory receptors [11] show elevated levels of male–male courtship (wing extension) or reduced male–male aggression (manifested as lunges) [17]. Conversely, activation of olfactory neurons expressing Or67d, the receptor for cVA, leads to elevated male–male aggression [13], suggesting that cVA promotes aggression. cVA also induces aggregation of males and females [13], and males show decreased courting over time of females perfumed with cVA [14].

Wang *et al.* [1] sought to understand the relative contribution of both smell and taste in mediating fly male–male interactions. Clearly, the detection of pheromones is essential to maintaining the proper balance between various social behaviors and more specifically to driving the correct behavior for the appropriate context. Which specific chemical cues mediate this balance, and how? Furthermore, both olfactory and gustatory cues affect similar behaviors — are these sensory systems redundant or do they interact in any way?

To examine these effects, Wang *et al.* [1] began by using a genetic manipulation that eliminated the majority of pheromonal cues on the male fly's cuticle, including the compound 7-tricosene (7-T), which has been shown to regulate male aggression [12]. Importantly, this mutation did not influence the production of the olfactory pheromone cVA, enabling the authors selectively to influence just one chemosensory modality (Figure 1A). The authors then examined the reactions of male, wild-type 'tester' flies to either male flies lacking the cuticular pheromones (oe– flies), 'perfumed' flies (oe– flies with reapplied cuticular compounds), or control flies (oe+ flies, no mutation present). Under these experimental conditions, the tester flies demonstrated opposite levels of behaviors in response to flies with the pheromones: they responded aggressively with low courtship toward oe+ flies, or with the 'perfumed' flies, but showed decreased levels of aggression and elevated levels of courtship towards mutant flies lacking cuticular pheromones. This inverse effect on aggression and male–male courtship by the cuticular pheromones was mediated by the compound 7-T.

To determine the chemosensory receptors mediating the behavioral responses to 7-T, Wang *et al.* [1] examined bitter-sensing gustatory receptor neurons, in particular those expressing the gustatory receptor (Gr) 32a, mutations of which have been shown to increase male–male courtship [18]. Males expressing a mutated form of the Gr32a receptor showed decreased levels of aggression compared to males expressing the intact Gr32a receptor, but no difference in the low levels of courtship towards wild-type, oe+ males. Courtship did increase towards oe– males perfumed with 7-T, implicating that other cuticular pheromones, and receptors other than Gr32a, may be involved in suppressing courtship. Nonetheless, the Gr32a receptor was required for the changes in male social behavior elicited by 7-T, suggesting that, at the least, Gr32a may be a 7-T receptor. In a final clever experiment, the authors expressed a capsaicin receptor (TRPV1) in

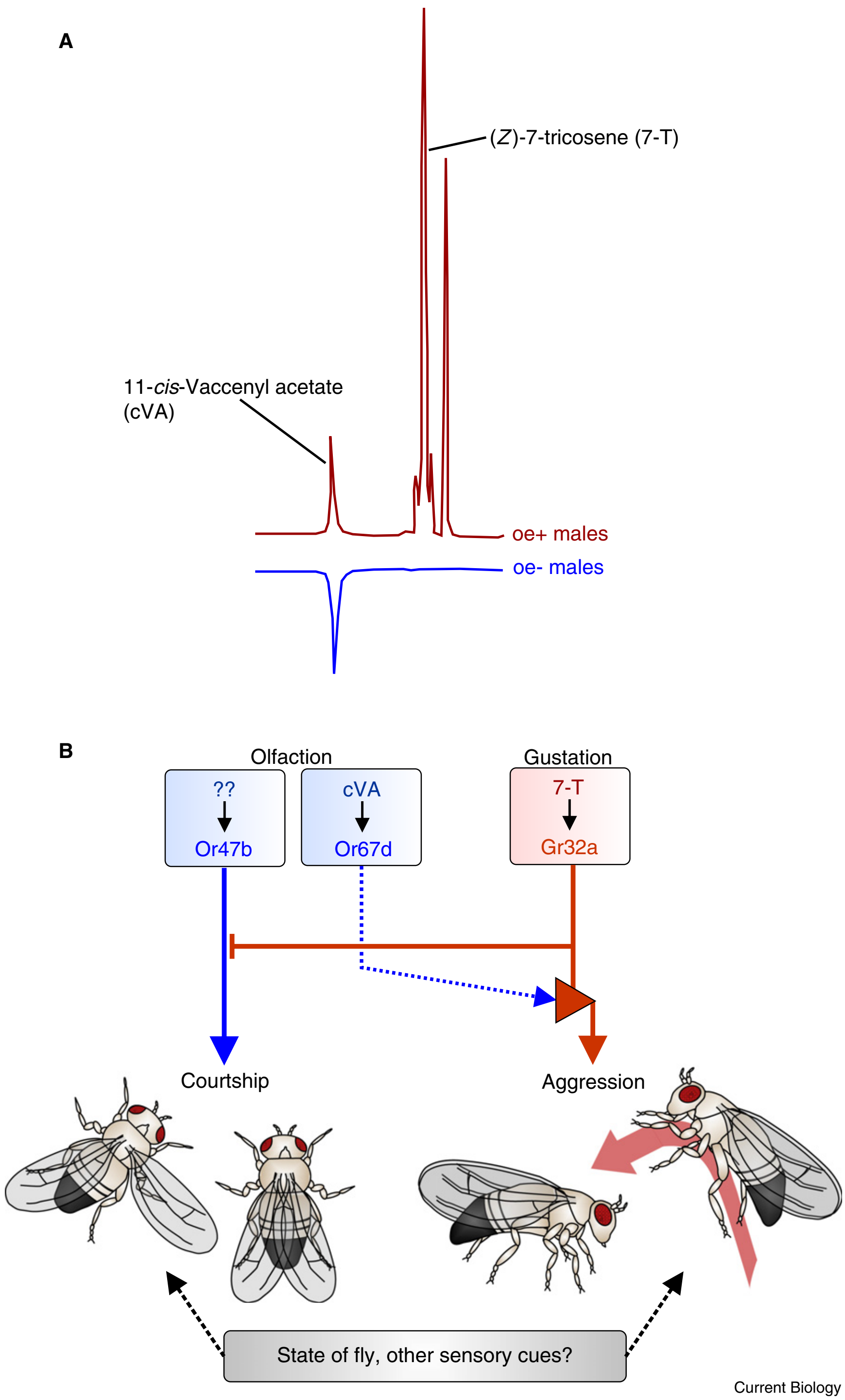

Figure 1. Pheromonal control of fly social behavior.

(A) Typical ion chromatogram showing the cuticular pheromone components of an oe+ 'control' male (top, red trace), and an oe- male (bottom, blue trace). oe+ males have the full complement of non-volatile cuticular hydrocarbon pheromones — especially the compound 7-T, which elicits aggression in males — whereas oe- males lack the cuticular pheromones. Both fly types emit the airborne pheromone cVA. (B) Illustration showing the proposed interaction between gustatory and olfactory systems. 7-T/Gr32a are necessary and sufficient for the aggressive 'lunging' behavior in flies (solid red arrow). By contrast, cVA/Or67d are sufficient, but not neccessary, for aggression (dashed blue arrow) and is 'gated' by the activation of Gr32a (depicted by the triphasic logic gate; red triangle). 7-T/Gr32a also inhibits the courtship behavior (wing-extension), mediated by Or47b and an unknown odorant (solid blue arrow). By 'gating' the two olfactory channels the 7-T/Gr32a system effectively drives social interactions in males, but how other sensory systems and the behavioral state of the flies influence these behaviors remains to be tested.

Gr32a-positive neurons — thereby allowing their activation by capsaicin — to demonstrate the sufficiency of these neurons for eliciting the increased aggression and decreased courtship behaviors.

While these results show the importance of gustatory pheromones in mediating male–male behaviors, how do olfactory cues — also shown to be important in mediating aggression by males — regulate these interactions? The olfactory pheromone cVA has been shown to increase aggression by activation of the olfactory receptor Or67d [13]. Wang *et al.* [1] found that the gustatory receptor Gr32a is necessary for the cVA aggression-promoting behavior, with Gr32a mutant flies showing no increase in aggression when exposed to cVA. By contrast, males with a mutation in the cVA receptor Or67d showed normal levels in aggression in response to 7-T, thus suggesting that the Gr32a pathway is necessary for, or 'gates', the response to cVA, whereas the response to 7-T is independent of cVA (Figure 1B).

Further research has shown that several olfactory receptors respond to odors present in males and females, and one of those receptors, Or47b, has been suggested to be involved in social behaviors such as courtship [19]. To determine whether a similar hierarchical interaction between taste and smell regulates courtship, Wang *et al.* [1] examined the contribution of Or47b in mediating courtship behaviors in the presence and absence of the cuticular hydrocarbon pheromones. They found that the presence of Or47b was critical for promoting male–male courtship when tested with flies lacking the cuticular hydrocarbon pheromones, but the presence of the cuticular pheromones was sufficient to inhibit courtship. It remains uncertain whether the 7-T cuticular pheromone similarly gates the Or47b pathway. Nonetheless, taken together, these results show that the olfactory system cannot on its own affect male–male interactions, but requires the presence of gustatory cues as well. The taste system somehow 'gates' the activity of these olfactory mediated behaviors (Figure 1B).

Rather than going on a series of 'blind dates' with little information about the appropriateness of the other individual, flies use their gustatory and olfactory systems to inform themselves whether they should fight or attempt to mate with another fly. Results from this study [1] are a first step towards showing the particular importance of gustatory pheromones in mediating other chemosensory systems. It brings forward many more questions, including: what are the the neural substrates and circuits involved in 'gating' the olfactory *versus* gustatory systems? Moreover, if gustation is as dominant a sense as it appears, cVA seems to be an almost redundant, unnecessary cue in male–male interactions. What additional information does cVA provide? Finally, previous research has demonstrated that auditory and visual cues are also involved in both courtship and aggression [15,20] — do they similarly inhibit, or are they inhibited by, the gustatory system? Because sensory integration, or 'fusion', is of such fundamental importance for any animal's behavior, such studies will help illuminate the general principles of the neurobiology controlling these behaviors across other taxa.

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Tendon Homeostasis: The Right Pull

Mechanotransduction, the conversion of a biophysical force into a cellular response, allows cells and tissues to respond to their mechanical milieu. How muscle force is translated through TGF-β signaling to regulate tendon homeostasis offers an interesting *in vivo* example of mechanotransduction.

Amnon Sharir* and Elazar Zelzer

Tendon disorders, injuries and degeneration are prevalent and pose a significant health problem [1]. Current understanding of the mechanisms involved in tendon disorders and repair is limited, resulting in relatively poor