AMAZING PAPERS IN NEUROSCIENCE
Cockroaches Now Evading Death by Getting Bitter about Sweeteners

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Here, I review the article "Changes in taste neurons support an adaptive behavior in cockroaches" by Wada-Katsumata et al. (2013). Their article elucidates the mechanism by which some cockroaches avoid eating poisoned bait: a change in the response properties of cells that transduce the tastant glucose and related sugars. Specifically, the data show that in cockroaches that avoid glucose consumption, these sugars activate the gustatory neurons that detect the presence of bitter compounds. This finding was replicated in cockroaches from several distinct populations. The article is brief but compelling. It serves as an excellent teaching tool for the topics of taste perception, neural mechanisms of behavior, and the rapid evolutionary response in terms of an adaptation of a sensory system to changing environmental conditions. Moreover, it could serve as a point of departure for a variety of in-class discussion topics.

Key words: behavioral mechanism; cockroach; electrophysiology; gustatory receptor neurons; polymorphism; sensory adaptation; taste

Wada-Katsumata et al.'s (2013) research article "Changes in taste neurons support an adaptive behavior in cockroaches" describes a mechanism by which cockroaches avoid poisoned baits. In the paper, Wada-Katsumata et al. (2013) first convey the problem: over a period of several years, some cockroach populations have evolved the trait of taste aversion to the sugar glucose, which is typically included as a phagostimulant in poisoned baits. They next review the insect's peripheral taste mechanisms, having put forth the hypothesis that the behavioral mechanism is dependent upon sensory transduction of glucose. Their recordings from several classes of gustatory receptor neurons (GRNs) reveal differences in the response patterns of bitter- and sweet-GRNs. Specifically, the bitter-GRN (which signals the presence of bitter tasting compounds and responds to the presence of caffeine) of "wild-type" (WT) cockroaches (cockroaches that are not particular about their dietary sugars) is unresponsive in the presence of fructose or glucose. In contrast, the bitter-GRN of "glucose-averse" (GA) cockroaches does respond to the presence of glucose (but importantly, still caffeine and not fructose). Next, they present concentration-response curve data that indicate the feeding behavior of animals from WT and GA strains differs when certain concentrations of particular glucosides are present. Their hypothesis is supported by electrophysiological evidence that suggests these differences in behavioral patterns can be explained by differences in the responses of bitter- and sweet-GRNs. By collecting field samples and examining their behavioral and neural (GRN) responses to several sweet and bitter compounds, the researchers demonstrate that a similar mechanism has arisen in multiple populations of cockroaches. The authors close by predicting that changes in the tuning of bitter-GRNs' gustatory receptors are the underlying molecular mechanism.

VALUE

Wada-Katsumata et al.'s (2013) paper is one of very few primary research articles that reveal the neural mechanism of a behavior so directly, though recent neuroethology textbooks do well at summarizing such research (e.g., Platt and Ghazanfar, 2012; Sillar et al., 2016). Other interesting behaviors for which a mechanism was revealed in a single primary research paper include the sea slug withdrawal reflex (Kupfermann and Kandel, 1969), crayfish escape behavior (Zucker et al., 1971), and the alternate behaviors of mating or attacking in mice (Lin et al., 2011; Lee et al., 2014).

What sets Wada-Katsumata et al.'s (2013) paper apart? Foremost: the phenomenological weirdness: how can a sugar taste bitter? Second, the question has broad societal impact and importance for the human behavior of responding to pests. Cockroaches, which serve as a vector for multiple diseases, colonize human living spaces all over the world and have developed resistance to some airborne insecticides that were once effective for population control (Rozendaal, 1997; Shahraki et al., 2013). Using sugary baits laced with flavorless insecticides has been effective until recently (Wada-Katsumata et al., 2013). Some of these notorious pests have begun to avoid the baits, and our response might be more effective if we can learn why. The scope of the problem of cockroach infestations and the potential impact of Wada-Katsumata et al.'s (2013) findings on pest control policies in general likely contributed to this paper's inclusion in *Science*. Third, the hypothesis that the behavior arises from an evolved sensory system adaptation is supported by data in the form of behavioral and physiological correlates. The extent of replication across distinct field samples from distinct locations is striking, and suggests many cockroach populations are generating similar responses to the human behavior of setting poisoned bait.

The data reported in the four figures and supplemental materials are clear and convincing. Though multifaceted, the individual panels are simple and intuitive enough for students to work through them with some help. One shortfall of this paper, or another positive note depending upon perspective, is the sequestering of statistical reporting to the supplemental materials. The supplemental videos of WT and GA cockroaches' behavioral responses to glucose and fructose make for a captivating introduction to the topic and this specific behavior.

The data reveal that the evolved glucose avoidance behavior's mechanism is the responses of particular peripheral neurons and their circuitry that does not require learning. However, the molecular and genetic bases of this adaptation remain unclear. Because these mechanisms remain unresolved, students in methods and advanced topic courses can be given the opportunity to propose follow up studies that draw on other techniques that would explain what has changed in GA cockroaches' GRNs.

That the research was carried out without the use of particularly cutting-edge techniques helps to make this article accessible for students with little background in neuroscience, especially when paired with a brief reading on the methods utilized by Wada-Katsumata et al. (2013) that is geared toward individuals with less expertise than *Science*'s intended audience. Most neuroscience textbooks include a basic explanation of electro-physiological techniques, which provides students with sufficient background to understand the recordings, though some of my students have asked for more detailed readings on such techniques (e.g., Carter and Shieh, 2015). Many students will therefore be able to gain an understanding of how the physiological recordings reveal the mechanism of the glucose-aversion behavior.

AUDIENCE

Presentations on Wada-Katsumata et al.'s (2013) paper can be tuned for a variety of audiences. In an introductory or interdisciplinary course, the article could be used to talk about how we perceive sugars and sugar additives as tasting "sweet" but also distinct from one another. In methods courses, the paper can be used to highlight reproducibility in science for the extent of replication across sugar compounds, the number of field samples tested, and the consistency of field samples' results with those obtained from laboratory samples. For class discussions, biodiversity, genetic engineering, population control and mechanisms of evolutionary adaptations are points of departure from this article. In my *Mechanisms of Behavior* course, we covered the article in depth with a focus on the relationship between behavioral and neural responses to the tastants. In my *Perception* course, I emphasized a comparison of the genetics, anatomy, and perception of taste across species (similar to the diversity of sight mechanisms) by tying Wada-Katsumata's (2013) paper to a discussion of human bitter taste polymorphisms (e.g., Soranzo et al., 2005; Wooding, 2005). To further cater to students who prefer to focus on humans, I would remind them that cockroaches and humans do frequent the same kitchens.

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