appear to be essential for anhydrobiosis. Attention is now focusing on various 'omic' approaches to the study of anhydrobiosis [5] to explore whether there is a 'desiccome' — a set of genes associated with desiccation survival and anhydrobiosis [6]. Of particular interest is desiccation-induced protein synthesis and the role of *lea* (*late embryogenesis abundant*) genes [19].

So will *C. elegans* dauers prove a useful model for the study of anhydrobiosis? Undoubtedly, but with a note of caution. The desiccation survival abilities of dauer-constitutive mutants are modest with 10% survival after exposure to 0% RH, following preconditioning at 98% RH. The survival of wild-type dauers is even lower [10]. Nematodes have a range of desiccation survival abilities [14], even within the same genus [20]: some will survive direct exposure to 0% RH with high levels of survival ('innate dehydration strategists' [14]). Perhaps our understanding of anhydrobiosis will be advanced by comparing the biology of organisms with different abilities to survive desiccation and anhydrobiosis.

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Associative Memory: Without a Trace

Some transient sensory stimuli can cause prolonged activity in the brain. Trace conditioning experiments can reveal the time over which these lasting representations can be utilized and where they reside.

Emmanuel Perisse and Scott Waddell

Associative learning allows an animal to know that the presence of a stimulus — the conditioned stimulus or CS, such as a smell or taste — predicts another is forthcoming — the unconditioned stimulus or US, a reward or punishment. Since the classic experiments of Pavlov [1], we have known that associative conditioning is most efficient when the CS and US presentations overlap in time (delay conditioning). However, learning can also occur when there is a pronounced gap between the CS and US (trace conditioning). Perhaps the most extreme case is in conditioned taste aversion learning in rodents, where the onset of malaise minutes to many hours after tasting a substance leads to a robust and long-lasting taste avoidance memory [2]. More subtle cases involve learning with a CS–US interval of minutes or seconds [1,3]. Importantly, such learning requires that following cessation of the CS, a representation or 'trace' remains in the nervous system that can be functionally associated with a later US so that a memory is formed. Understanding how and where stimulus 'traces' manifest in the nervous system and how they are incorporated into memory is of considerable interest. Animals with relatively simple and manipulable nervous systems may be useful for this endeavour.

Two recent studies [4,5] investigated trace conditioning using olfactory associative learning and physiological approaches in the honeybee and fruit fly. Bees quickly learn to extend their proboscis to odors following association of that odor with a sucrose reward [6,7]. In a similar manner, flies learn to avoid an odor that was previously associated with an electric shock [8]. Using variants of these established training protocols, both groups investigated parameters of 'trace' conditioning. Flies could learn a ten second odor stimulus when punished fifteen seconds afterwards, whereas bees could remember a half second odor pulse when rewarded six seconds later. Surprisingly, unlike other animals [3,4,9,10], bees remembered after only one trial of trace

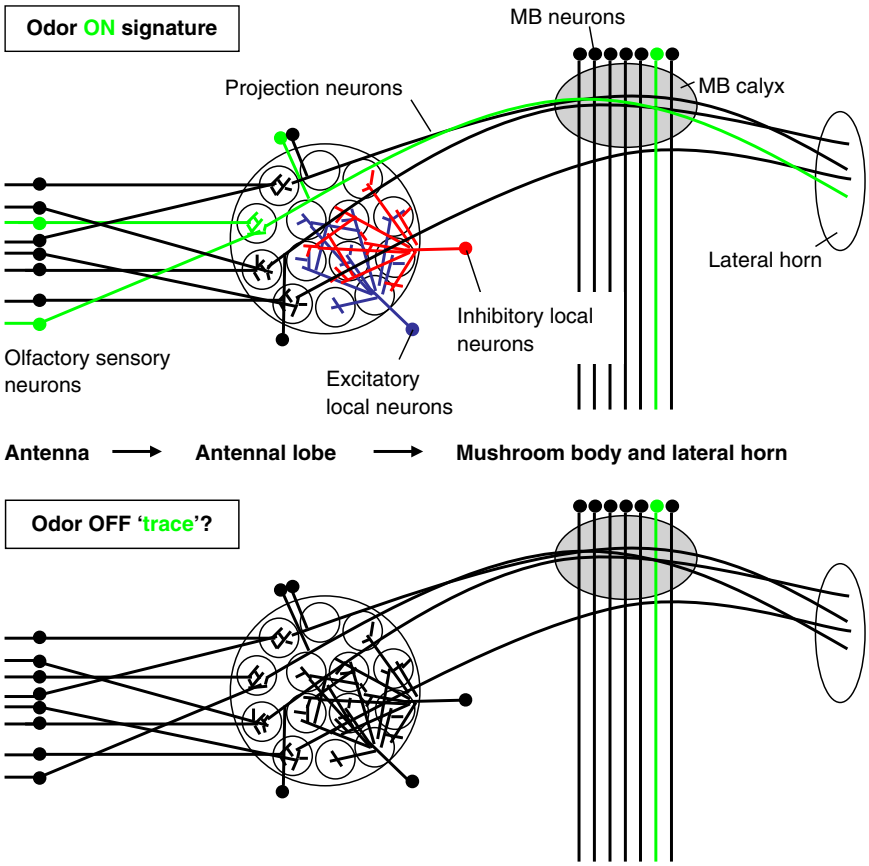

Figure 1. Schematic of the insect olfactory system.

Odor exposure activates unique combinations of olfactory sensory neurons (green). These neurons activate specific glomeruli in the antennal lobe engaging inhibitory (red) and excitatory (blue) local neurons and combinations of projection neurons (green). Projection neurons carry odor information to the mushroom body (MB) calyx where signals are transformed into activation of a small fraction (green) of the population of mushroom body neurons. Trace conditioning could utilize a lasting odor trace in mushroom body neurons (green). Adapted with permission from [20].

conditioning [5]. The ability to condition bees with a single trial indicates that learned associations likely involve a lingering CS 'trace' rather than a prediction error-driven adjustment of the reinforcement system [11].

One of the most interesting and apparently conserved features of trace conditioning is that performance can be improved by prior experience [9,10,12]. Successful trace conditioning with a particular time interval can extend the interval that can be bridged in subsequent trials. Conditioning bees or flies with a shorter interval between CS and US improved future learning with a time gap that was too long for naïve animals to learn. Interestingly, a previous trial of delay conditioning did not facilitate future trace conditioning in bees. It therefore appears that flies and bees benefit from being familiar with the relevance of a gap between the stimuli. In effect they have recognized and learned one of the important 'rules' of the learning task so that they are able to maintain the utility of the CS trace for longer. Such a scenario is reminiscent of the concept of a pre-established mental schema or framework, which facilitate encoding, storage and consolidation of new associations in rats [13]. Establishing the neural mechanisms accounting for these, at least superficially, similar phenomena will be of great interest.

What are the neural correlates of the 'trace' that allow it to be associated with a temporally delayed US? Given that both the fly and bee learning tasks involve an olfactory CS, it seems likely that remnants of the odor representation will reside in the circuitry of the olfactory system (Figure 1). Indeed, prior work has indicated that odor responses remain in the bee or fly antennal lobe — the first center of insect olfactory processing — following the odor stimulus [14,15]. Furthermore, the similarity of odor responses in the antennal lobe is well correlated with the perceived similarity of odors following delay conditioning [16]. Both of the new studies [4,5] therefore used calcium (Ca^{2+}) imaging to look for a CS trace in the bee or fly antennal lobe after the odor delivery was terminated.

Although the post-odor responses were reproducible and odor-specific, the similarity of their combinatorial profiles did not correlate with the odors perceived as similar by the animals following trace conditioning. Therefore, the authors [4,5] concluded that neither the primary olfactory receptor neurons of the fly nor the second order projection neurons of the bee maintained informative odor representations following the stimulus. Is this lack of a correlation enough to write off the neurons in the antennal lobe as potentially representing a CS trace? Certainly the data suggest that these Ca^{2+}-dependent signals in the antennal lobe are not a good candidate to inform us of the nature of persistent odor traces in the nervous system. However, the antennal lobe circuitry might hold odor traces in a more complex temporal manner than that evident using Ca^{2+} imaging. Additionally, the odor traces might be represented amongst a larger antennal lobe neural ensemble and/or in Ca^{2+}-independent intracellular signalling cascades within the relevant neurons. Lastly, given the apparent importance of the mushroom body for classical olfactory learning in the bee and fly, one might imagine the mushroom body to be the most likely site to locate prolonged associable odor traces that would also correlate to perceptual similarity. However, potential odor traces in the mushroom body might also be more complex than activity-evoked fluctuations of Ca^{2+} [17].

It is also conceivable that trace conditioning in bees and flies will involve neural circuitry that is not employed during routine delay conditioning. In mammals, trace conditioning recruits additional neural structures such as the hippocampus [10,18]. Although the reason is not fully understood, a simple explanation

could be that the hippocampus is required to solve a more difficult task [3]. The hippocampal circuitry has been proposed to support a neuronal reverberation that holds the CS representation long enough for the animal to "bridge the gap" between the CS and US presentation. A conceptually similar mnemonic reverberant circuitry has been proposed to exist amongst subsets of fruit fly mushroom body neurons maintained by broadly arborizing excitatory dorsal paired medial neurons and inhibitory anterior paired lateral neurons [19]. It would be straightforward to test whether the function of this mushroom body circuitry is required to hold the odor trace and thereby permit olfactory trace conditioning in the fly. With this sort of analysis we might catch a glimpse of the elusive odor trace.

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Adaptive Introgression: The Seeds of Resistance

Populations of the European house mouse have acquired resistance to anticoagulant pesticides from a closely related species. This discovery improves our understanding of the circumstances in which interspecific genetic exchange is likely to facilitate adaptation.

Loren Rieseberg

My favorite paper as a graduate student was a review by botanist, Charley Heiser [1], titled "*Introgression re-examined*", in which he evaluated the role of interspecific gene exchange (introgression) in evolution. Botanists had long viewed introgression as a potent evolutionary force that promoted the development and acquisition of novel adaptations [2,3]. However, zoologists were more skeptical and typically emphasized the frequently negative fitness consequences of hybridization [4]. Despite his botanical background, Heiser [1] was forced to conclude that while introgression "*may play a very significant role; it must be admitted, there is as yet no strong evidence to support such a claim*."

The strong evidence Heiser was looking for has been a long time coming. Molecular marker studies over the past three decades have shown that introgression is widespread in plants and animals [5–7], vindicating earlier botanical views about the porous nature of reproductive barriers [1–3,8]. However, convincing evidence of adaptive introgression has been more difficult to obtain. The paucity of examples might be due to the challenge of marshalling the diverse data sets required to demonstrate that introgressed alleles or traits have been favored by selection [9–11]. Alternatively, it might be that adaptive introgression is rare. A paper by Michael Kohn and colleagues [12] in this issue of *Current Biology* not only furnishes exceptionally strong evidence of adaptive introgression involving Old World mice, but it also provides insights into the circumstances under which introgression is likely to facilitate adaptive evolution.

Theory indicates that for many species — especially those with large populations — variation created by mutation is likely to exceed that provided by introgression [13]. Thus, introgression is thought to promote adaptation mainly through the transfer of favorable sets of genes rather than individual mutations. A familiar example of the latter — albeit involving horizontal gene transfer rather than sexual hybridization and