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Zombies, Invertebrates, and Plants, Oh My! Introduction to the Special Section on "Learning: No Brain Required"

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Historically in behavior science, laboratory research with nonhuman animals has concentrated heavily on mammalian (e.g., rats, primates) and avian (i.e., pigeon) species. Thus, our body of work has been conducted with species with a well-developed central nervous system (CNS), which consists of a spinal cord and brain. One presumed benefit of research with animals such as these is generality to humans, because our species shares considerable neural architecture with theirs. Less intuitively obvious is the generality of such research to the more than 95% of species that are invertebrates (Lewbart, 2006). The biodiversity of invertebrate species, which spans protozoa, sponges, jellyfish, worms mollusks, insects, spiders, and sea urchins, suggests that the behavioral processes they possess have been fundamentally important to their survival, and likely to ours as well.

Behavior science historically has shown limited concern with the workings of the CNS. Skinner (1938, 1953) cautioned heavily about conceptualizing the brain as a causal agent of behavior, focusing more on external environmental events that change both behavior and the brain, with heavy emphasis on the former. Nonetheless, there are many ties between contemporary neuroscience research and a behavior science account of brain–behavior interactions (Ortu, 2012; Thompson, 2008; Zillo, 2016). In particular, the fields of behavioral pharmacology and toxicology, which began in 1955 with the publication of Peter Dews's seminal articles in the *Journal of Pharmacology and Experimental Therapeutics,* incorporate neural substrates into an understanding of drug and toxicant action on behavior (e.g., Dews, 1955). Rooted in behavior science, these disciplines suggest that the careful characterization of behavior may require consideration of what is also happening in the brain. Both areas have evolved into independent disciplines, each with their own journals and professional organizations. The connections to behavior science remain, however. Behavioral pharmacology researchers regularly contribute to the *Journal of the Experimental Analysis of Behavior* and numerous special issues on behavioral pharmacology and neuroscience have appeared

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in the journal (e.g., September 1991, March 1994, and November 2005). The Association for Behavior Analysis International (ABAI) also supports a Neuroscience Special Interest Group. Behavioral pharmacology is one of the success stories of our science, finding a place for study of the nervous system with another science (pharmacology; Laties, 2003).

On Zombies and Supposedly "Brainless" Creatures

The title of this special section of the second issue of *PoBS* is meant to be attention-grabbing and provocative. Indeed, the editorial staff of *PoBS* planned for the special section to arrive around Halloween, as it has been affectionately referred behind-the-scenes as "the zombie issue." This tongue-in-cheek reference alludes to the extent to which the undead, whose CNS is in questionable shape, might learn. Attributes of the zombie, such as human flesh as a possible reinforcer and their seeming lack of behavioral sensitivity to aversive stimuli, delightfully entertain. However, they also occasion questions that are relevant to the wealth of research conducted on invertebrates, plants, and even spinally transected organisms: To what extent do purportedly "brainless" creatures learn? What kinds of learning might they exhibit? And what kind of nervous system, if any, is required? Might we need to reexamine our current understanding of learning?

Many "brainless creatures" exhibit behavioral change in the face of environmental feedback. Indeed, in behavioral neuroscience, invertebrates have been used in "simple-systems" approaches in which specific neurons or ganglia involved in learning processes (see Carew & Sahley, 1986) are isolated and neural and behavioral mechanisms involved in learning can be explicitly examined. These species have been critically important in assisting our understanding of the basic processes of sensitization, habituation, classical conditioning, and operant conditioning at both the behavioral and neural levels. The pivotal work of Eric Kandel with *Aplysia* is a solid example (e.g., Carew, Hawkins, & Kandel, 1983; Kandel & Schwartz, 1982; Walters, Carew, & Kandel, 1981). In addition to *Aplysia*, learning is also documented in a range of other invertebrates, including mollusks, cephalopods, and crustaceans; moreover, basic learning processes have also been shown in a range of insect species (e.g., Dixon, Daar, Gunnarsson, Johnson, & Shayter, 2016; Guerrieri & d'Ettorre, 2010; Hammer, 1993; see also the article by Abramson and Wells in this special section). Nonetheless, the ability to characterize dynamics at two levels of analysis (behavioral and neural) is one of the hallmarks of a strong animal model (Tordjman et al., 2007).

What of other species that are nonanimal? Slime molds are single-celled amoeba that have many nuclei, and thus do not have neurons. Yet, it has been reported that they are able to 1) move toward food sources in a U-maze (Reid, Latty, Dussutour, & Beekman, 2012; Reid et al., 2016) and 2) avoid the slime they emit as they move (slime appears to be a natural aversive). In doing so, they are able to find the shortest and least aversive paths to food. Moreover, slime molds also show habituation to the aversive stimuli of quinine and caffeine (Boisseau, Vogel, & Dussutour, 2016).

Plants also lack a central nervous system, but some research suggests that they may learn. The Cornish mallow (*Lavatera creticacan*) rotates its leaves toward the sun, but it does so at night—before the sun comes up (Schwartz & Koller, 1986). Note that this response is not in reaction to light, which is characteristic of a tropism, but seemingly "in anticipation" of a stimulus, suggesting learning. In addition, neutral cues, such as a fan, can be conditioned to light as an unconditioned stimulus in plants, resulting in possibly classically conditioned growth of seedlings (Gagliano, Vyazovskiy, Borbély, Grimonprez, & Depczynski, 2016). Plants can even respond to aversive stimuli. Although they are not able to escape by moving in response to the destruction of leaves by predators (or experimenters with scissors), they send chemical signals that require glutamate-like receptors. The signal begins at the site of the damage and relays to other parts of the plant, activating stress hormone, thereby turning on genes that induce the plant's physical defenses (Muday & Brown-Harding, 2018). Of course, whether these examples truly qualify as learning is a subject of debate. In the current issue of *PoBS*, the article by Adelman and Axelrod's review of Peter Wohlleben's *The Hidden Life of Trees: What they Feel, How They Communicate* outline the relevant arguments and evaluate some of the claims on the extent to which plants learn.

The Purpose of this Issue

The special section "Learning: No Brain Required" serves several purposes. First, this issue reports on research and philosophy from a variety of disciplines related to learning in invertebrates. We also include research on learning in nonanimals (see articles by Adelman and Axelrod). We also include work on learning in animals with transected spinal cords (see Brumley, Strain, Devine, & Bozeman), a different circumstance of learning without input from a brain. This broad selection of research provides an opportunity for those in our field to question and possibly expand our current understanding of key learning concepts—even fundamental notions such as what constitutes *behavior* and *learning*, and what counts as a *learner*. The first article of the series by Burgos describes some of these issues and raises some important philosophical questions that nicely frame the remainder of the articles.

Second, the special issue has practical implications. The use of vertebrate species in research has declined in the United States over the last 30 years (Speaking of Research, 2015; U.S. Department of Agriculture, 2016), presumably because of animal rights activism, declines in federal funding for research (Federation of American Societies for Experimental Biology, 2018), and the use of computational models as alternatives to the use of animals. Figure 1 shows that the decline continued in recent years. Sustaining animal laboratories may continue to be a problem for behavior scientists, and it is one that may require some creative solutions.

From the standpoint of animal research sustainability, it may be important for behavior scientists to consider a wider range of species for their laboratories—species that include invertebrates—as solid models for phenomena. One benefit of using invertebrate species is that they are often less expensive (depending on the species) than vertebrate species. In addition, invertebrate laboratories may be less likely to be targeted by activism. Moreover, invertebrates are not protected under federal (and often local) animal research regulations; the policies and procedures for their use in research is less strict. Despite their benefits, though, determining appropriateness and adequacy for using invertebrates as models is also important. In the current issue of *PoBS*, van Staaden and Huber's article shows that drug reinforcer efficacy can be modeled nicely in crayfish. Deochand, Costello, and

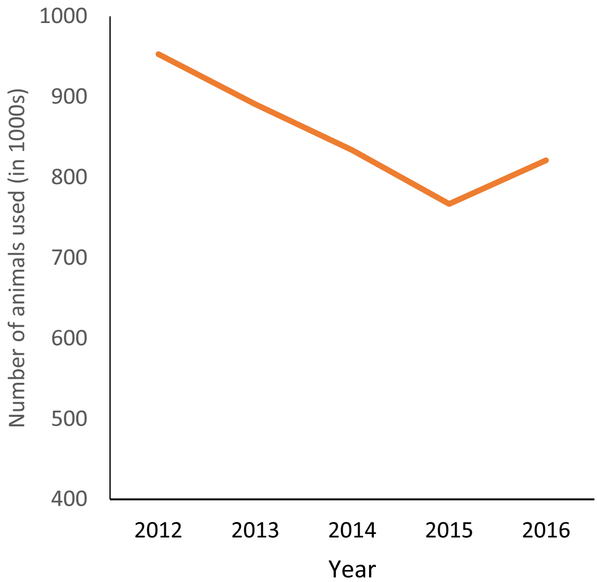

Fig. 1 Shows the number of animals in thousands used in research in the United States, 2012–2016 (USDA, 2016).

Deochand's article on the use of plenaria in research also provides some convincing arguments on why flatworms would be excellent research tools.

Finally, the contingencies of the survival of a scientific discipline are many. The current federal funding climate suggests that interdisciplinary research is critical to research sustainability. In other words, grant dollars are more likely to be awarded to applicants that attempt to research questions from more than one scientific perspective. If laboratory and applied behavior scientists can forge collaborations with other disciplines that share common ground, such as those that use a wider variety of species, then more behavioral research is likely to be funded. More funding leads to more published research, which leads to more funding, and so forth. This cycle increases the discipline's chances of survival. Perhaps "brainless" creatures might be able to teach us about survival on several levels.

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