Study sheds light on relationship between environment, hormones and evolution

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Pelobates cultripes *Spea multiplicata* *Scaphiopus couchii*

These three species of spadefoot toads metamorphose differently. The first two species from the left are able to regulate the timing of their metamorphosis by modulating hormone production. The species on the right has a fixed period for their metamorphosis. It's all thanks to the ponds they live in. Credit: Robert Denver

Different species of spadefoot toads approach metamorphosis differently, and it's all thanks to the pond they grew up in, according to a team of researchers that includes a University of Michigan scientist.

The researchers found that some species can regulate the timing of their metamorphosis by regulating hormone production, while the timing of other species is fixed.

Their study, published in *Nature Communications*, is one of the first to provide a mechanism—in this case, the differences in the ways metamorphosis is controlled by hormones in different species of spadefoot toad—that underlies a theory called genetic accommodation. The theory was introduced more than 15 years ago by Mary Jane West-Eberhard, an evolutionary biologist who completed all of her degrees at U-M, says study author Robert Denver, a U-M developmental neuroendocrinologist.

In this theory, when organisms of any kind—microbes, plants or animals—experience changes in their environment, over time, that organism may change its phenotype, or its physical characteristics, that develop in reaction to its environment. West-Eberhard suggested that differences between species and new phenotypes can evolve through the changing of their ancestral phenotype. These changes then become fixed through the process of genetic accommodation.

The spadefoot toad species Pelobates cultripes can induce metamorphosis when it senses its pond drying up in order to escape as a juvenile toad. Credit: University of Michigan

"For this to work, the ancestors must have had the capacity to express a range of phenotypes in response to different environments, a process known as phenotypic plasticity or developmental plasticity." said Denver, professor and chair of the U-M Department of molecular, Cellular and Developmental Biology.

For example, the way humans look can vary depending on their diets, stress, or a number of other factors.

"We all have a genotype, or genes, that code for proteins that ultimately determine what we look like and what the capacity is for our growth. But within that, there's a range of body sizes that can be achieved based on the environment," said Denver, who is also a professor of ecology and evolutionary biology. "As the environmental values shift towards the extremes, natural selection may favor phenotypes that are better able to make a living in the new environment."

In the toads Denver studied, the key was in whether the ponds of water the tadpoles hatched into were permanent or short lived.

The spadefoot toad species Spea multiplicata can induce metamorphosis when it senses its pond drying up in order to escape as a juvenile toad. Credit: University of Michigan

The researchers discovered that the species of spadefoot toad that live in semi-permanent ponds can trigger their own metamorphosis when they

sense that their pond is drying up. The activation of their thyroid glands spurs metamorphosis, just as in humans, but the toads also activate their adrenal glands. This produces a stress hormone that accelerates metamorphosis, allowing the tadpole to escape the drying pond and move onto land as a juvenile adult.

Other species of spadefoot toads breed in ephemeral pools—for example, pools of water in the Arizona desert that exist for only a few days. These species have a very short developmental period that cannot be altered by the environment that they live in.

The shorter larval period of the spadefoot toads that breed in the ephemeral pools also affects their size as adults. The spadefoot toads that breed in semi-permanent ponds are about the size of half dollars when they metamorphose, while the other species is about the size of a dime, Denver said.

Denver says the common ancestor of spadefoot toads was most likely able to modulate the timing of its metamorphosis, but when some spadefoot toads started living in extremely challenging, arid environments, they shifted their developmental period to a very short, fixed one.

The spadefoot toad species Scaphiopus couchii lives in ephemeral ponds and cannot regulate the timing of its metamorphosis. They can go from hatching to metamorphosis to able to breed in about 10 days. Credit: University of Michigan

"Their ancestors likely had the capacity to metamorphose over a range of time, for example from two weeks to three months or more," Denver

said. "But over time, either their habitat became much drier, or they happened to move into these dry environments, and the individuals who survived there were the ones that had this very short developmental period."

In the drier environments, natural selection favored the individual toads with very rapid development but lacked the capacity for varying their rate of development in response to their environment. Instead, their endocrine systems are active much earlier in development, and their tissues became much more sensitive to the hormonal signal.

"Our study is one of the few examples of a physiological/developmental mechanism underlying genetic accommodation," Denver said.

Denver conducted the research with co-authors Saurabh Kulkarni and Daniel Buchholz in the department of biological sciences at the University of Cincinnati, and Ivan Gomez-Mestre at the Doñana Biological Station in Spain.

More information: Saurabh S. Kulkarni et al. Genetic accommodation via modified endocrine signalling explains phenotypic divergence among spadefoot toad species, *Nature Communications* (2017). DOI: 10.1038/s41467-017-00996-5

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