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Behind the Scenes: Size Tradeoff: Horns vs. Copulatory Organs

By **Armin Moczek, Indiana University**
 posted: 19 September 2008 09:17 am ET

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This Behind the Scenes article was provided to LiveScience in partnership with the National Science Foundation.

It began with an idea as old as Charles Darwin. In 1859, Darwin surmised in "The Origin of Species" that natural selection, the competition between individuals within a population for survival, might have many parallels to the competition between growing organs as they develop inside a young organism — success of one would have to come at the expense of another.

I have always been fascinated by these "resource allocation trade-offs" because they explain much about how an organism's growth affects how it evolves. If there is a limited pool of resources to build parts, building one part larger must mean other parts end up smaller. If evolution favors the enlargement of one part, this may only be possible by the compensatory reduction of another. As intuitive as this mechanism seems, the evidence for it was muddy. Past work showed resource allocation trade-offs occur in laboratory experiments and in populations undergoing artificial selection experiments. How common and important they are in nature remained unclear.

In 2000, this old idea was fortuitously joined by two important observations, one from a laboratory experiment, the other from field measurements. At the time I worked with a [species of beetles](#) in which males grow large horns, much like antelopes. But only males do it, so to study the development of horns during earlier developmental stages — the larva — I had to somehow be able to determine the sex of beetles while they were still immature.

The sex of beetles

I found a group of cells in the abdomen of about half of all larvae that I thought might give rise to the male copulatory organ. This group of cells doesn't exist in females. To be sure, I used a surgical technique to destroy these cells without otherwise injuring the animal, kind of like a dermatologist removes a wart. I then waited for larvae to turn into adults.

Lo' and behold, all the animals that had those extra cells became males, and all the larvae that I did surgery on became males lacking a copulatory organ. But I also made an additional observation. Males who had their copulatory organ precursor cells surgically removed ended up growing significantly longer horns. Somehow, altering the growth of one structure affected the development of another —on the other end of the animal.

The second observation came from natural populations. My beetle species is native to Italy, but had been introduced to the Eastern United States, Eastern Australia, and Western Australia less than 50 years ago. When studying these isolated populations, I found that they had all diverged in the relative sizes of their horns. Males from the Eastern United States grew by far the [largest horns](#), whereas Western Australian males grew the smallest, with the other populations' horn sizes in between.

Horn length and female access

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Shown are dung beetle males of two of the 10 Onthophagus species examined in the study. From top to bottom: O. gazella (South Africa) and O. sagittarius (Indonesia). Credit: Armin Moczek

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I found good explanations for why horn sizes had changed so much. Male beetles use their [horns as weapons](#) against rivals so they can gain access to females. In Western Australia, however, competition between males was so intense that most males were better off not fighting and instead engaged in "sneaking" behavior, in which case shorter horns was better. In the Eastern United States, competition between males was moderate, and most males performed better by being fighters and having long, powerful horns. Horn length therefore appeared to have evolved due to changes in the behavioral conditions of fighting males. The question now was whether that was the end of the story.

These two observations met Darwin's old idea when Harald Parzer (a graduate student in my lab) and I set out to determine whether the changes in horn investment we observed between these populations had also brought about changes in the sizes of copulatory organs. To do so, Harald measured body sizes and the lengths of horns and copulatory organs in several hundred males from the native as well as the three exotic populations. If both structures indeed develop somehow at the expense of each other, they should also have evolved at the expense of each other in these four populations, in other words: the population with the largest horns should have the smallest copulatory organs and vice versa. This was exactly what we found!

Enduring tradeoffs

We found the same result when we extended our analysis to [different species](#) rather than populations. Harald examined males from 10 different species, all of which differ in how much their males invest into horns. Their investment into copulatory organs inversely mirrored that investment: as before, the species with the largest horns had the smallest copulatory organs and vice versa.

Our results showed that such tradeoffs are real, that they occur in natural populations, that they can be visible extremely early after just 50 years of isolation between populations, but that they remain visible for millions of years after species have long separated from each other. And that connected, for the first time, the developmental tradeoff between horns and copulatory organs to the evolution of new species.

It turns out copulatory organs are a funny structure. They don't just [transmit sperm](#) during copulation; they are also believed to somehow determine who can successfully mate with whom.

In insects, species appear to diverge first in the shape and size of their copulatory organs, and numerous otherwise cryptic species can only be told apart by their copulatory organs. If populations of the same species would, for some reason, evolve different-sized copulatory organs, these populations may subsequently find it hard to interbreed and ultimately evolve into separate species.

Our study provides evidence that the first part of this scenario appears to happen in nature. We now want to know if the second part is also true. Are Eastern United States and Western Australia populations less able to interbreed because of the different sizes of their male copulatory organs? Are these populations on their way to become separate species? If so, if it is indeed that easy to initiate speciation in these organisms, we may finally be able to explain why beetles are the most species-rich group of organisms on this planet, accounting for a fifth of all living species and a fourth of all named animals.

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Editor's Note: *This research was supported by the National Science Foundation (NSF), the federal agency charged with funding basic research and education across all fields of science and engineering. See the [Behind the Scenes Archive](#).*

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TheWooj wrote:

So all those guys who do things to try and look all macho... yeah, we knew you were compensating...

posted 9/19/2008 4:46:19 PM

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solace_rage wrote:

Yeah, these beetles trading off horns for organs, and growing shorter horns to be sneaky, that kind of crazy.

posted 9/19/2008 5:10:44 PM

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Skeptic_Believer wrote:

What a waste of time! A stupid article, I might say. Sorry, guys, but for me, I've got more important things to do than be interested in the "The Sex of Beetles". Find another job Armin Moczek.

posted 9/23/2008 1:11:37 AM

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posted 9/23/2008 1:13:40 AM

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RedSmirk wrote:

This is amazing... a real example of the tradeoff hypothesis, AND possibly speciation occurring right in front of us. Wonderful example of how environmental pressures (lack of females in this case) can change the physicality of the next generations. Skeptic_Believer needs to study more evolution to get the really exciting part of this article.

posted 9/26/2008 11:11:31 PM

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HermesTrismegistus wrote:

I'm wondering what the Intelligent Design people would say about this. I guess God enlarges one horn so the beetle won't feel so bad about missing the other one.

posted 9/30/2008 1:34:07 PM

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