Using math to examine the sex differences in dinosaurs

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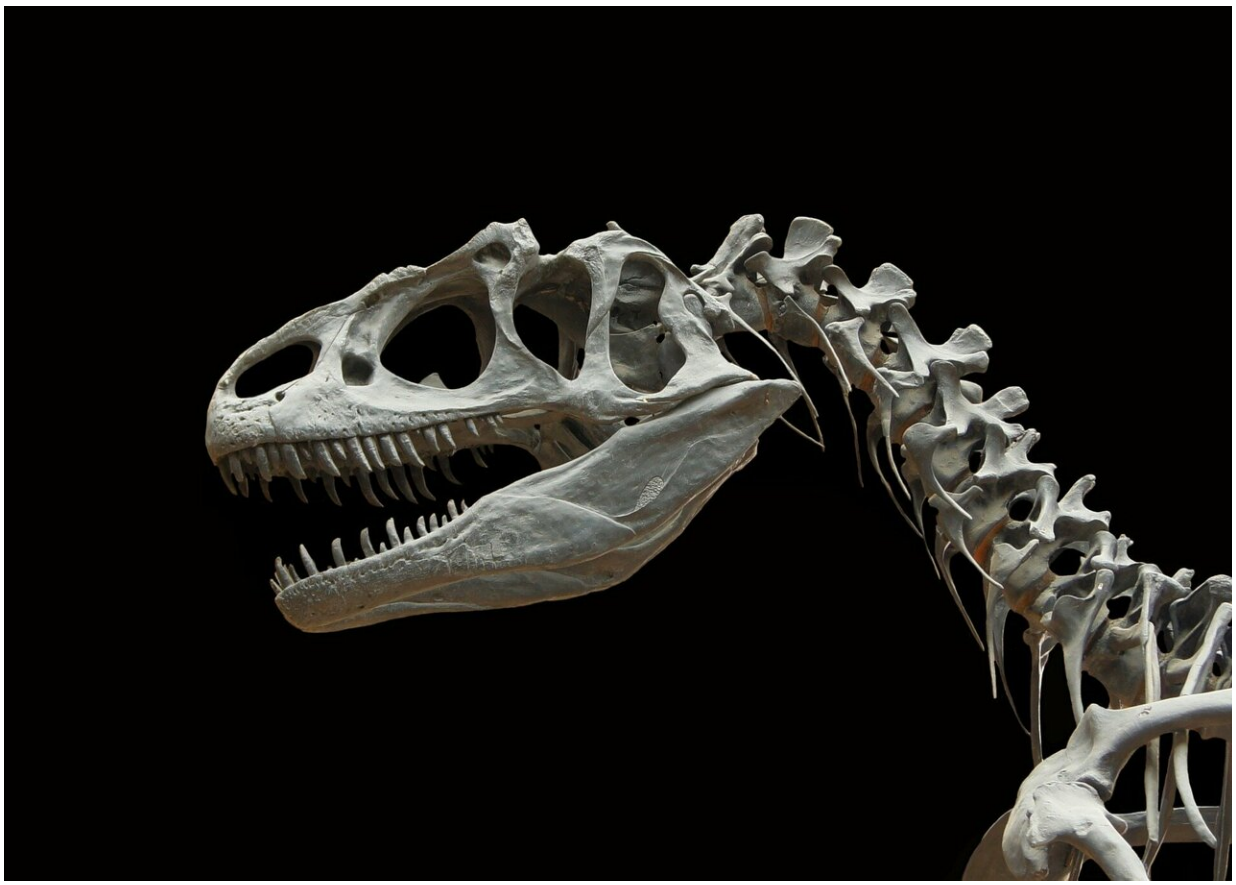

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Male lions typically have manes. Male peacocks have six-foot-long tail feathers. Female eagles and hawks can be about 30% bigger than males.

But if you only had these animals' fossils to go off of, it would be hard to confidently say that those differences were because of the animals' sex. That's the problem that paleontologists face: it's hard to tell if dinosaurs with different features were separate species, different ages, males and females of the same species, or just varied in a way that had nothing to do with sex. A lot of the work trying to show differences between male and female dinosaurs has come back inconclusive. But in a new paper, scientists show how using a different kind of statistical analysis can often estimate the degree of sexual variation in a dataset of fossils.

"It's a whole new way of looking at fossils and judging the likelihood that the traits we see correlate with sex," says Evan Saitta, a research associate at Chicago's Field Museum and the lead author of the new paper in the *Biological Journal of the Linnean Society*. "This paper is part of a larger revolution of sorts about how to use statistics in science, but applied in the context of paleontology."

Unless you find a dinosaur skeleton that contains the fossilized eggs that it was about to lay, or a similar dead giveaway, it's hard to be sure about an individual dinosaur's sex. But many birds, the only living dinosaurs, vary a lot between males and females on average, a phenomenon called sexual dimorphism. Dinosaurs' cousins, the crocodilians, show sexual dimorphism too. So it stands to reason that in many species of dinosaurs, males and females would differ from each other in a variety of traits.

But not all differences in animals of the same species are linked to their sex. For example, in humans, average height is related to sex, but other traits like eye color and hair color don't neatly map onto men versus women. We often don't know precisely how the traits we see in dinosaurs relate to their sex, either. Since we don't know if, say, larger dinosaurs were female, or dinosaurs with bigger crests on their heads were male, Saitta and his colleagues looked for patterns in the differences between individuals of the same species. To do that, they examined measurements from a bunch of fossils and modern species and did a lot of math.

Other paleontologists have tried to look for sexual dimorphism in dinosaurs using a form of statistics (called significance testing, for all you stats nerds) where you collect all your data points and then calculate the probability that those results could have happened by pure chance rather than an actual cause (like how doctors determine whether a new medicine is more helpful than a placebo). This kind of analysis sometimes works for big, clean datasets. But, says Saitta, "with a lot of these dinosaur tests, our data is pretty bad"—there aren't that many fossil specimens, or they're incomplete or poorly preserved. Using significance testing in these cases, Saitta argues, results in a lot of false negatives: since the samples are small, it takes an extreme amount of variation between the sexes to trigger a positive test result. (Significance testing isn't just a consideration for paleontologists—concerns over a "replication crisis" have plagued researchers in psychology and medicine, where certain studies are difficult to reproduce.)

Instead, Saitta and his colleagues experimented with another form of stats, called effect size statistics. Effect size statistics is better for smaller datasets because it attempts to estimate the degree of sex differences and calculate the uncertainty in that estimate. This alternative statistical method takes natural variations into account without viewing dimorphism as black-or-white-many sexual dimorphisms can be subtle. Co-author Max Stockdale of the University of Bristol wrote the code to run the statistical simulations. Saitta and his colleagues uploaded measurements of dinosaur fossils to the program, and it yielded estimates of body mass dimorphism and error bars in those estimates that would have simply been dismissed using significance testing.

"We showed that if you adopt this paradigm shift in statistics, where you attempt to estimate the magnitude of an effect and then put error bars around that, you can often produce a fairly accurate estimate of sexual variation even when the sexes of the individuals are unknown," says Saitta.

For instance, Saitta and his colleagues found that in the dinosaur Maiasaura, adult specimens vary a lot in size, and the analyses show that these are likelier to correspond to sexual variation than differences seen in other dinosaur species. But while the current data suggest that one sex was about 45% bigger than the other, they can't tell if the bigger ones are males or females.

While there's a lot of work yet to be done, Saitta says he's excited that the statistical simulations gave such consistent results despite the limits of the fossil data.

"Sexual selection is such an important driver of evolution, and to limit ourselves to ineffective statistical approaches hurts our ability to understand the paleobiology of these animals," he says. "We need to account for sexual variation in the fossil record."

"I'm happy to play a small part in this sort of statistical revolution," he adds. "Effect size statistics has a major impact for psychological and medical research, so to apply it to dinosaurs and paleontology is really cool."

Provided by Field Museum

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