Simple rule explains complex group swimming patterns

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A simple rule gives rise to coordinated swimming in zebra-fish as they become adults. Credit: Shira Lottem

Watching the smooth movement generated by hundreds of fish as they swim in unison is truly mesmerising. But it's not only its sheer beauty that makes it so hard to look away, for scientists, it's also the fact that its emergence is so difficult to explain. In an article published today (February 13, 2017) in the scientific journal *PNAS*, researchers from Champalimaud Centre for the Unknown (CCU), in Lisbon, present a surprisingly simple rule that explains how complex patterns of collective movement emerge in zebrafish as they develop from recently hatched larvae into adults.

"There are many models that try to explain how collective swimming emerges in groups of fish, but many of them fall short of the mark because of two main challenges." Says Gonzalo de Polavieja, principal investigator of the Collective Behaviour lab at CCU. "The first is obtaining a rich dataset where you can reliably track each individual in the group. This is quite difficult since fish move in three dimensions and are physically very similar. The more animals you want to observe at the same time, the harder it becomes. And the second, which is even more challenging, is constructing a model that doesn't only mimic the group behaviour, but actually captures the rules that the animals themselves use."

In this study, together with Robert Hinz, a doctoral student in the lab, de Polavieja applied an original approach to overcome these challenges. "Most studies focus on adult animals, where patterns of collective movement are the most striking. Instead, we decided to observe how the emergence of collective swimming happens as the animal develops. Though young zebrafish do not swim together often, they gradually develop shoaling and schooling behaviour during the first month of development, eventually forming large schools as adults. By following the fish from a young age, we were able to obtain a rich dataset that led us to discover a strong behavioural rule."

Using this extensive dataset and a sophisticated tracking method called idTracker, which was previously developed by this lab, the researchers tested a series of rules that might explain the behaviour, but to their surprise, the simplest rule was the one that prevailed - the rule of random attraction. "Theoretically, fish could use many different strategies to decide where to swim. They could choose swimming towards the fish closest to them, or the furthest, or towards a higher density of fish, we tested many options... But no, it turns out that they literally choose at random which fish to follow."

If the fish choose at random, why is it that young fish don't form schools, while the adults do? "We discovered that group patterns become more prominent in adults because, when compared with their younger selves, they spend less time swimming independently and more time following other fish." de Polavieja explains. "Though the rule of random attraction remains the same throughout development, younger fish spend only 1% of the time applying it. As they develop, that amount of time grows exponentially until it reaches 50% in the adult. Using this simple rule, adult animals are more likely to move towards high density of fish without lumping and group movement emerges."

According to de Polavieja, the model they developed doesn't only explains how the fish form collective movement, it also overcomes the second challenge, as it may be capturing the actual rule that the animals themselves are following. "It's easy to produce rules that make your models look like 'the real thing'. It's not cheating, but researchers often have to introduce extra parameters to their models so that they successfully mimic the data. The winner of the modeling world, however, is the model that has the fewest parameters but still successfully captures the data. The rule we found, though mathematically complex, has predictions that are independent of any fixed parameters, but only on the variables of the experiment, such as the number of fish in the tank, which makes it very strong indeed." He concludes.

More information: Ontogeny of collective behavior reveals a simple attraction rule, *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1616926114

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